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Issue 176

"This was a whopper of a nuclear bomb, and very different from any other type of explosion"

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Nuclear explosions
PAGE 26

By far the biggest explosions on Earth have been natural events – volcanoes and meteorite impacts. The 1815 Mount Tambora eruption, for example, released the equivalent energy of 33 billion tonnes of TNT exploding, while the impact that wiped the dinosaurs out 66 million years ago was thousands of times bigger than that, hitting Earth with the energy of around 72 trillion tonnes of TNT. This puts the yield of the USSR's 1961 Tsar Bomba, the world's most powerful nuclear test at 50 million tonnes of TNT, in the pale. All the same, this was a whopper of a nuclear bomb, and very different from any other type of explosion, human-made or otherwise. Learn more about the science and history of nuclear explosions on page 26. Enjoy!

Ben Biggs
EDITOR

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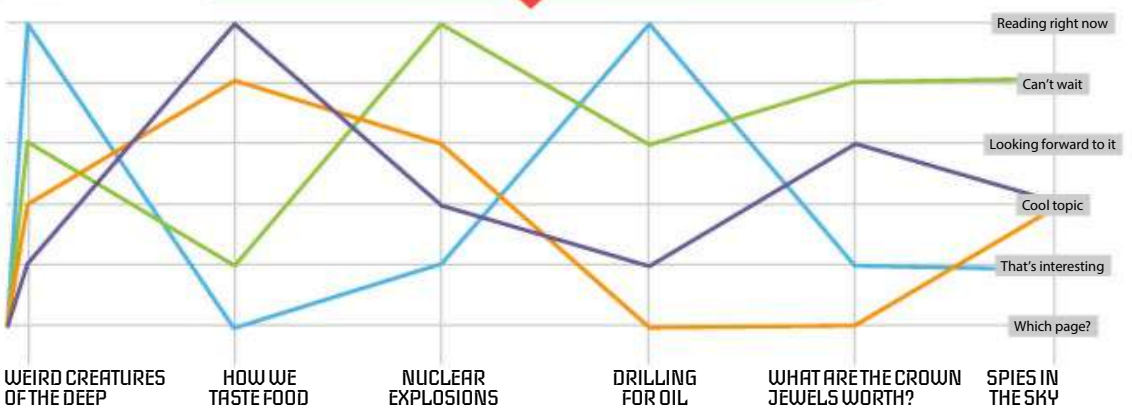

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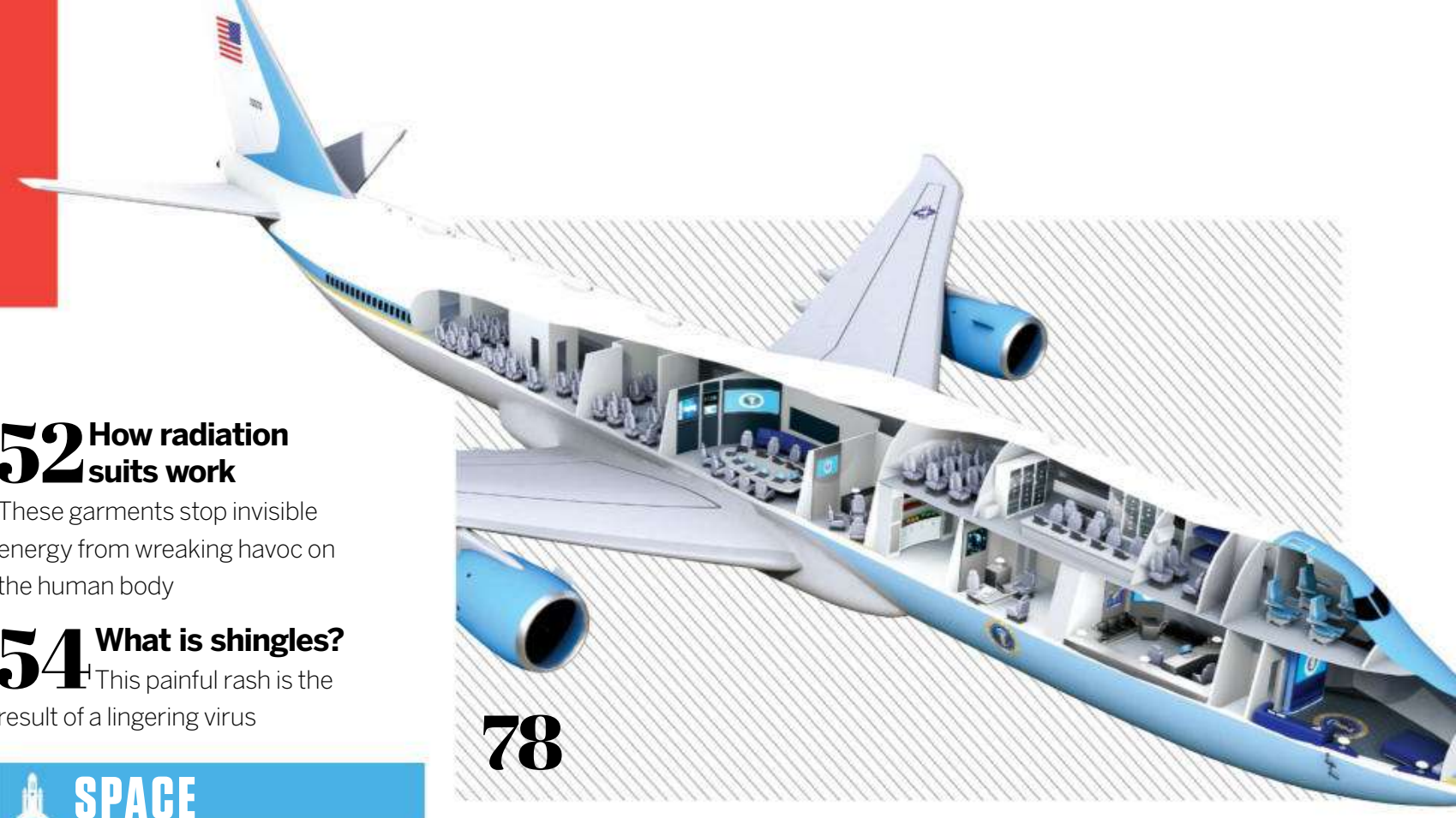

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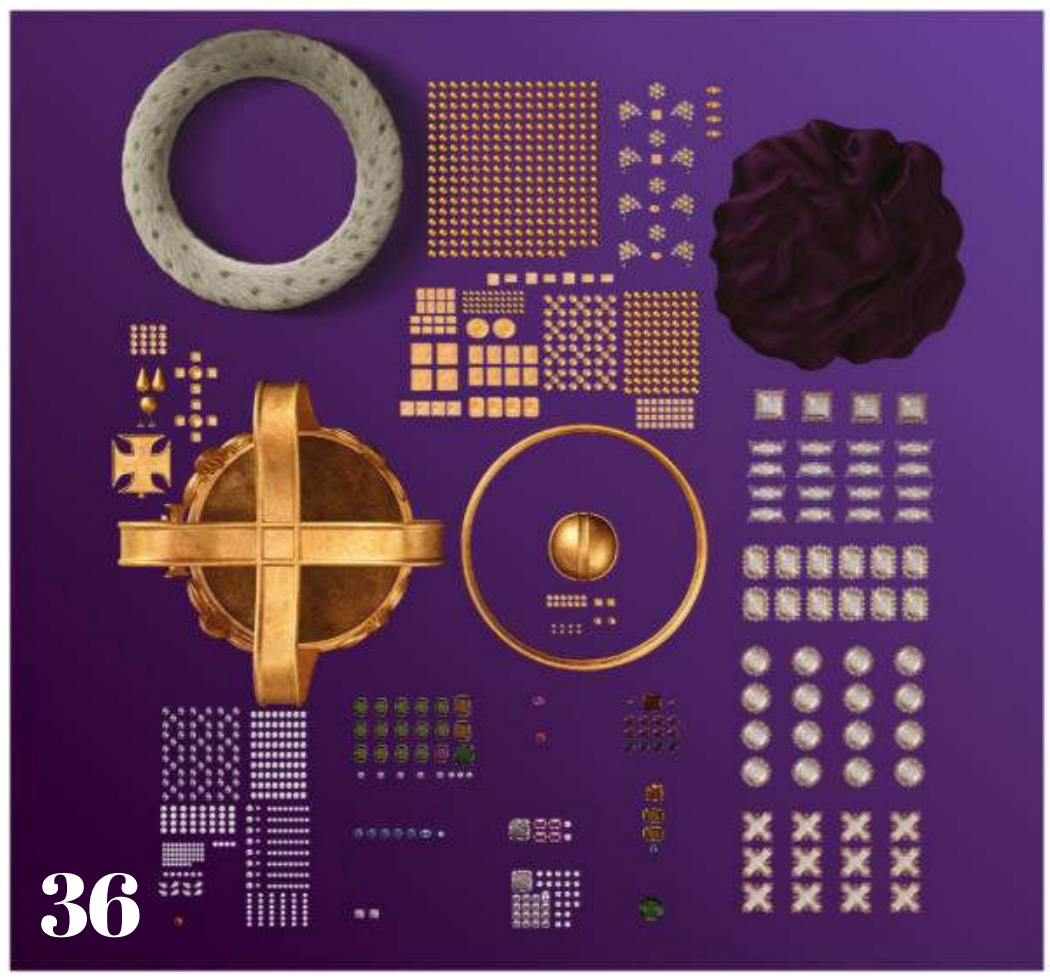

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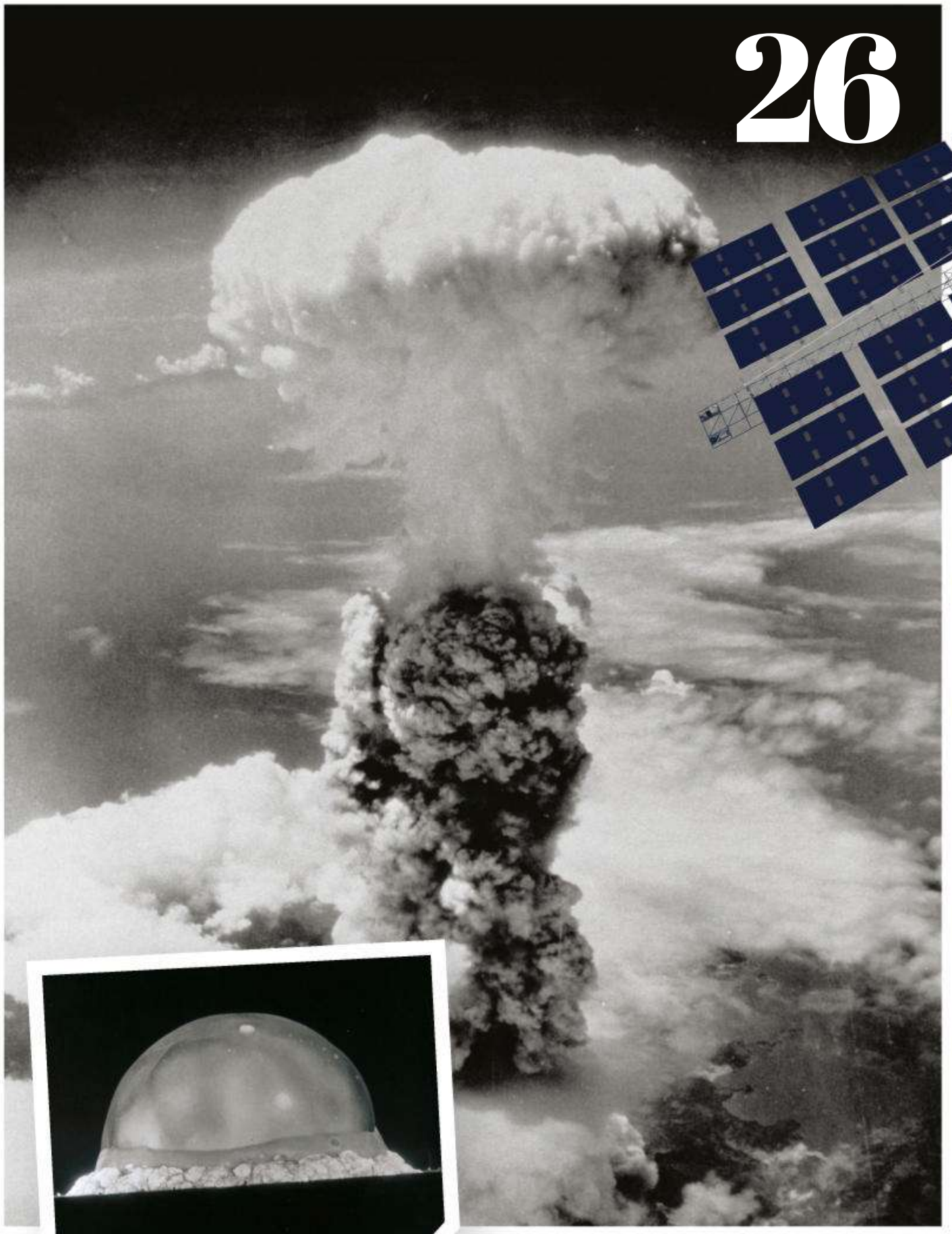
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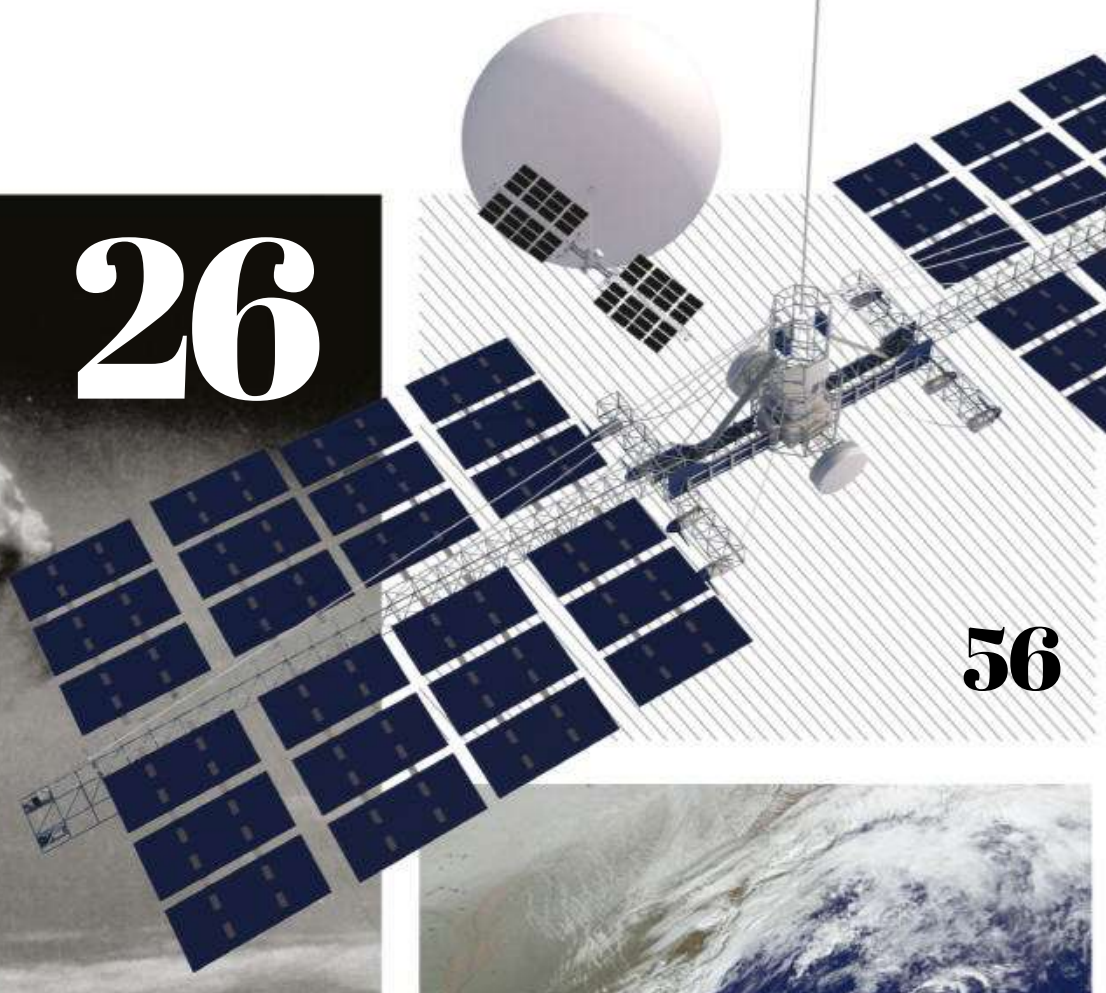
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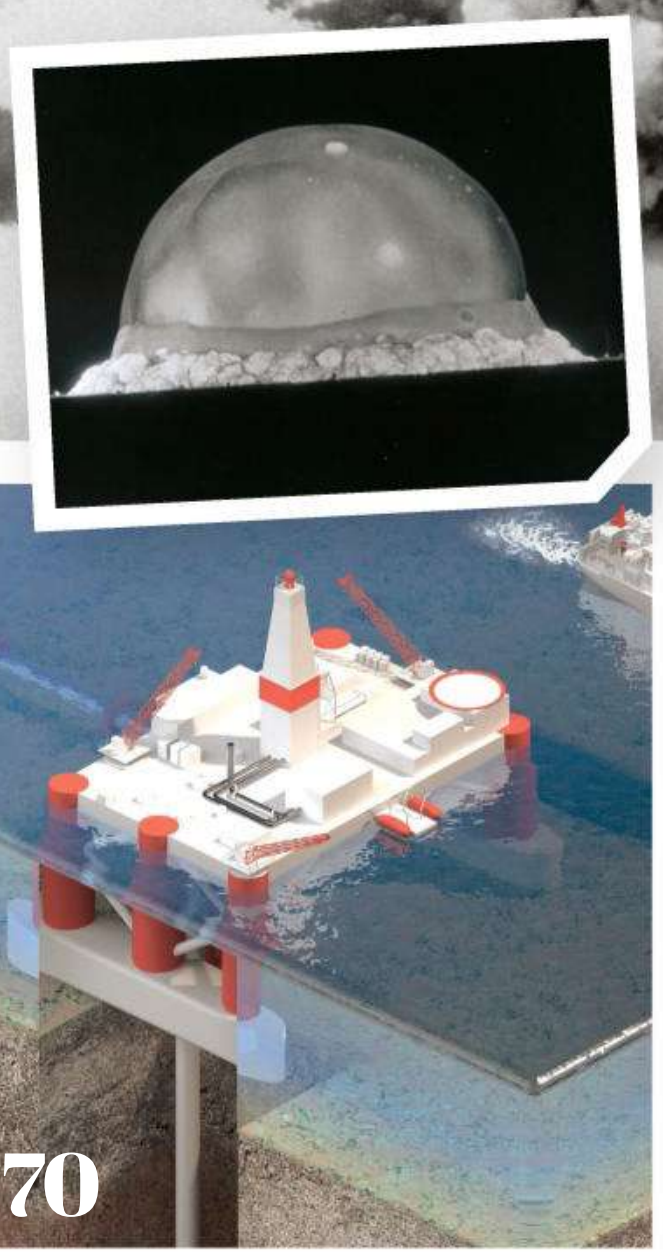

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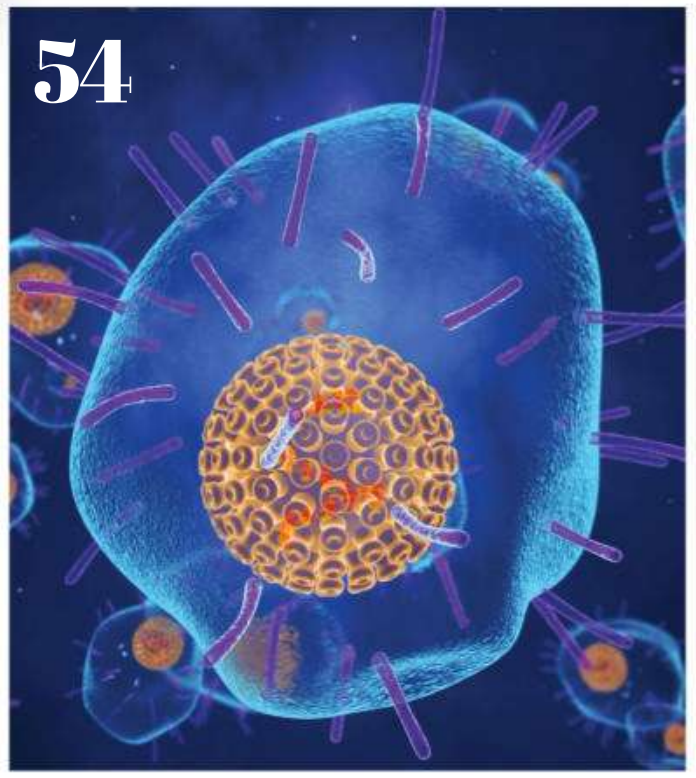
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Bees taking a break

After a busy day of plant hopping for delicious nectar, these cuckoo bees are taking a well-earned break on a branch. These bees share a particular parental trait with their avian namesakes. Female cuckoo bees are kleptoparasitic: instead of establishing a hive, they invade another, take it over and lay their eggs for another bee species to raise as its own.

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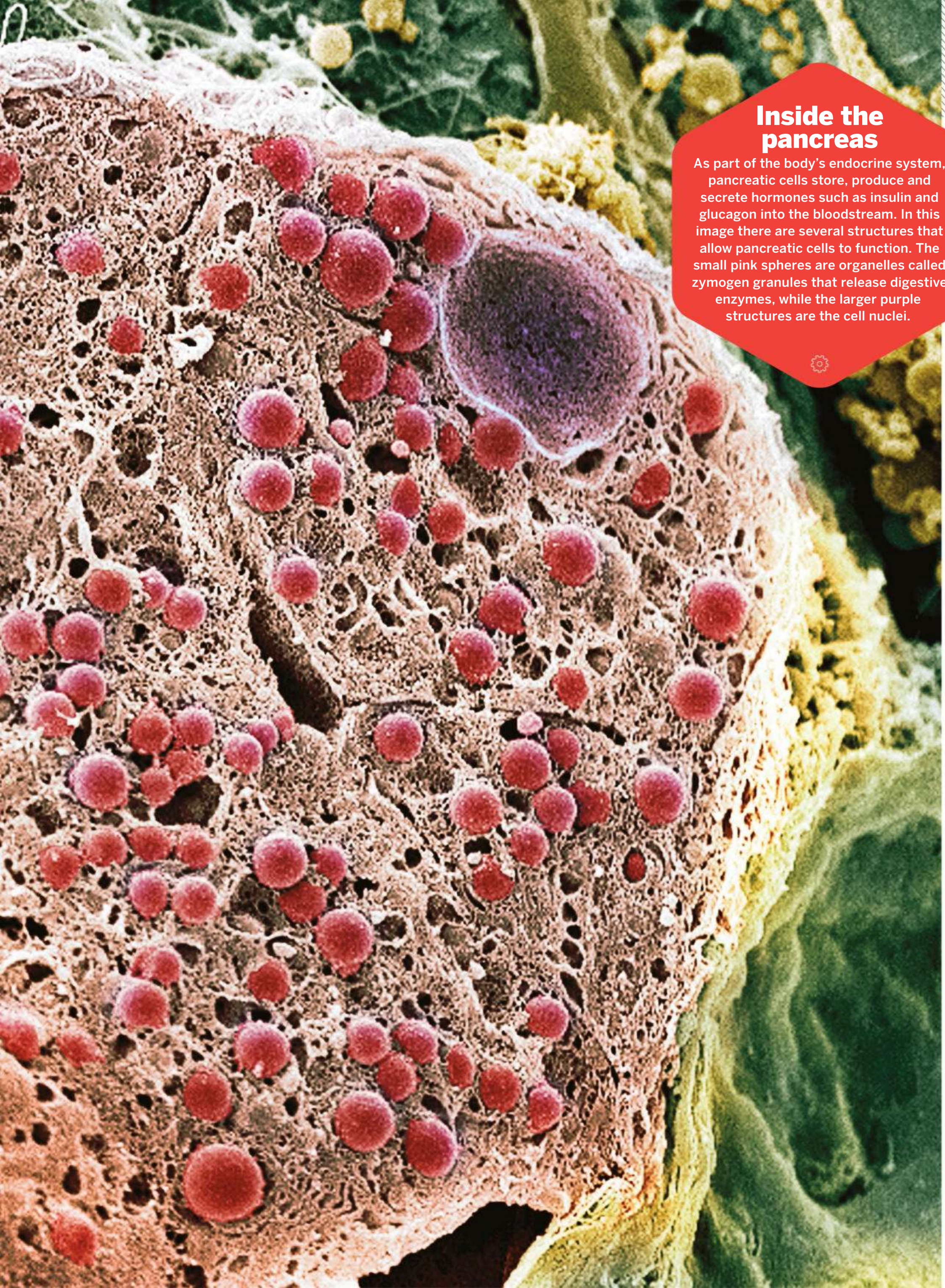

Inside the pancreas

As part of the body's endocrine system, pancreatic cells store, produce and secrete hormones such as insulin and glucagon into the bloodstream. In this image there are several structures that allow pancreatic cells to function. The small pink spheres are organelles called zymogen granules that release digestive enzymes, while the larger purple structures are the cell nuclei.

© Getty

Gentle eruptions

Snapped from the International Space Station (ISS), this aerial shot shows Chile's Villarrica volcano during a series of minor eruptions. Villarrica is one of South America's most active volcanoes and has been erupting since October 2022. In January 2023 astronauts aboard the ISS captured a mild 'Strombolian' explosion that ejected molten rock up to 100 metres above the volcano.

© ISS Crew Earth Observations Facility/Earth Science and Remote Sensing Unit/ Johnson Space Center

Space superbubble

The Hubble Space Telescope has captured a gap in the cosmos called a superbubble. The 250-light-year-wide hole can be found among the hydrogen gas and stardust of a nebula called N44. Although the exact cause of the superbubble remains unknown, it's been proposed that strong stellar winds emanating from the stars at its centre may be pushing the dust and gas outwards.

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SPACE

Groundbreaking volcanic activity on Venus detected

WORDS SASCHA PARE

A computer-generated image of the surface of Venus shows Maat Mons, a five-mile-tall volcano near the planet's equator that erupted in 1991

Planetary scientists have found evidence of recent volcanic activity on Venus. Archives from NASA's Magellan mission show telltale signs that Maat Mons, a five-mile-high volcano, was active in 1991. Magellan, launched in May 1989, was the first spacecraft to map the entire surface of Venus. The mission's radar images revealed that Venus is peppered with volcanoes, but at the time scientists couldn't tell whether any of them were still active.

Now, a new analysis of these 30-year-old archives has detected a volcanic vent swelling with lava in the Atla Regio region, near the planet's equator. The discovery was inspired by NASA's next mission to our sister planet, which will launch within a decade. VERITAS (Venus Emissivity, Radio science, InSAR, Topography and Spectroscopy), led by the agency's Jet Propulsion Laboratory in Southern California, will scan Venus from surface to core to understand how a rocky planet so similar to ours became a scorching hellhole.

"NASA's selection of the VERITAS mission inspired me to look for recent volcanic activity in Magellan data," said Robert Herrick, a research professor at the University of Alaska Fairbanks and member of the VERITAS team. "I didn't really expect to be successful, but after about 200 hours of manually comparing the images of different Magellan orbits, I saw two images of the same region taken eight months apart exhibiting telltale geological changes caused by an eruption."

Maat Mons is the tallest volcano on Venus, towering 8,000 metres above the barren volcanic plains and deformed terrain of the planet's surface. In a picture taken in February 1991, a volcanic vent associated with Maat Mons appears nearly circular, with signs of drained lava on its exterior slopes, and covers an area of less than one square mile. In October, Magellan captured the same vent brimming with a lake of bubbling lava – it was misshapen and had doubled in size. But the orbiter photographed the vent from different orbits and with poor resolution, making it difficult for the scientists to compare the images. They managed to line them up manually, however, and build computer models of the vents, which helped them determine what caused the geological changes.

"Only a couple of the simulations matched the imagery, and the most likely scenario is that volcanic activity occurred on Venus' surface during Magellan's mission," said Scott Hensley, a senior research scientist at NASA's Jet Propulsion Laboratory. "While this is just one data point for an entire planet, it confirms there is modern geological activity."

The gush of lava from Maat Mons' crater would have been similar in size to the eruption of Hawaii's Kilauea volcano in 2018, the researchers said. This finding gives scientists a taste of the discoveries NASA's upcoming mission will likely reveal. VERITAS is the first spacecraft to return to Venus since the 1990s. Its mission is to create 3D models of the planet to reveal its innermost secrets.

ANIMALS

Ancient monster fish was short and chunky

WORDS **CAMERON DUKE**

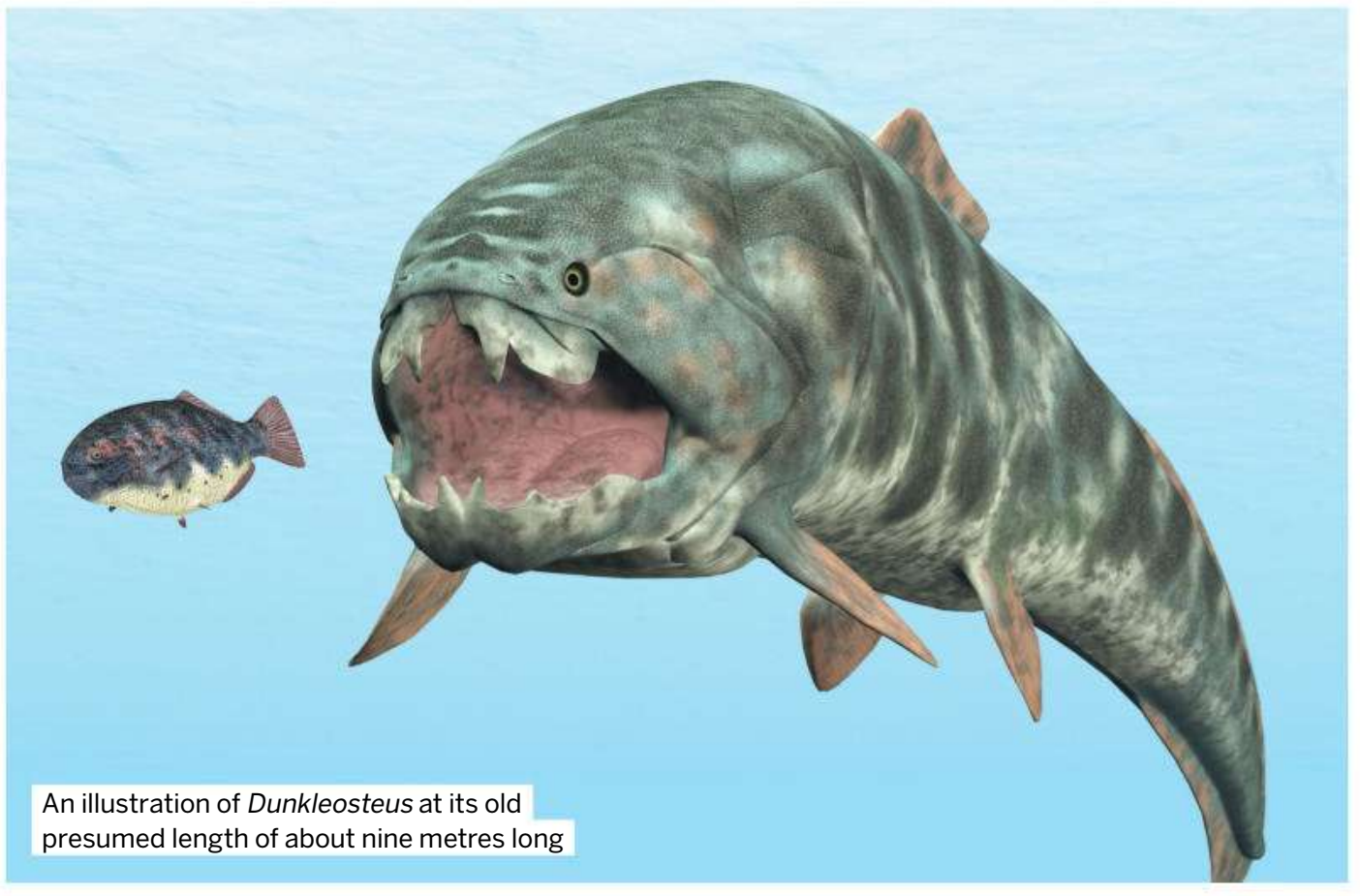
A 360-million-year-old sea monster that was once thought to be as big as a bus was actually less than half that long, but just as chunky. The bony fish *Dunkleosteus terrelli* was one of many superpredators that prowled the oceans during the Devonian period. This armoured fish, which prowled the oceans that once covered modern-day Ohio, had blade-like jaws that could snap shut with 3,600 kilograms of force. The first *D. terrelli* fossils were discovered 150 years ago along the shores of Lake Erie, and the largest known specimen resides in the collections of the Cleveland Museum of Natural History.

Unlike modern fish, which either have skeletons of cartilage or bone, *D. terrelli* had a bony, armoured skull attached to a skeleton of cartilage. Only the skulls of these creatures fossilised, so early researchers extrapolated *D. terrelli*'s size from the relationship between a shark's skull size and its body length. For the next 150 years, *D. terrelli* would become a local palaeontology icon. Yet very little scientific work focused on it. While studying the *D. terrelli* specimens in the Cleveland Museum of Natural History, Russell Engelman, a doctoral student at Case Western University in Cleveland, encountered a problem. No matter how he tried, Engelman couldn't reconcile the skull with a nine-metre-long body. "I tried using some of the old measurements, and biologically they just didn't make sense." Engelman said. All of his reconstructions required strange, unrealistic body proportions that looked nothing like the original drawings of *D. terrelli*. He decided to find out how the original researchers determined the size of *D. terrelli*, and that's when the problem became apparent. "I went back through the literature, and it turned out that most previous authors who had talked about this were basically just eyeballing it," Engelman said.

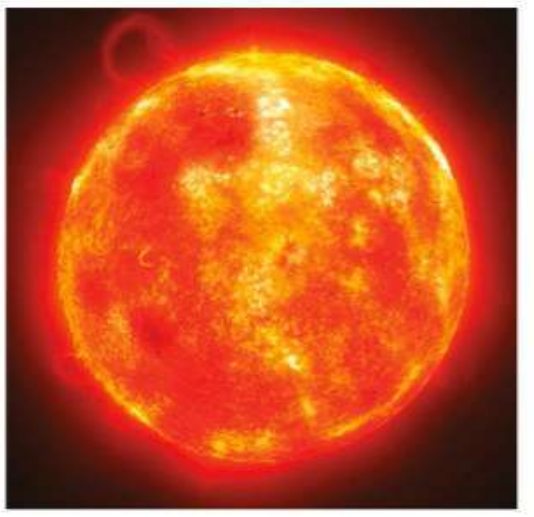
Did you know?

The Devonian period was 419.2 to 358.9 million years ago

So Engelman measured the dimensions of various fish skulls and compared them with their body proportions. He found that skull size and shape are highly correlated with body proportions. When applied to *D. terrelli*, this analysis didn't just rule out the most extreme size estimates, it ruled them all out. Instead of being nine metres long, *D. terrelli* was likely no longer than four metres. Engelman's analysis examined a lot of fishy factors, but it ultimately boiled down to the height versus the width of the skull. Fish with longer skulls tend to have more elongated bodies, while fish with shorter skulls have shorter bodies. *D. terrelli*'s relatively short head suggests it had a short, wide body, more like a tuna than a shark.



An illustration of *Dunkleosteus* at its old presumed length of about nine metres long



NASA's Solar Dynamics Observatory recorded the 'dark plasma' prominence hurling itself into space

SPACE

THE SUN SPEWS 'DARK PLASMA' INTO SPACE

WORDS **SAMANTHA MATHEWSON**

An explosion on the Sun spewed 'dark plasma' into space that resulted in a moderate geomagnetic storm on 15 March. The eruption was detected on 11 March by coronagraphs at NASA's Solar Dynamics Observatory (SDO) and on the Solar and Heliospheric Observatory (SOHO), an Earth-orbiting spacecraft co-operated by NASA and the European Space Agency. SOHO spotted a dark stream of plasma, known as a coronal mass ejection (CME), that emerged from the southwestern limb of the Sun. Dark plasma is cooler and less luminous than the background Sun and denser than the gas surrounding it in the Sun's atmosphere.

The data from the coronagraph shows snowy dots and streaks that represent the energetic particles accelerated by shock waves in the CME. They create short-lived luminous speckles when they hit SOHO's sensors. The coronagraph view also captures the planet Mercury. The effects of this CME were indeed seen on Earth in the form of aurorae and a moderate and a short-lived G2-class geomagnetic storm.

These particles were funnelled by Earth's magnetic field towards our planet's poles in what is known as a polar cap absorption event. The storm disrupted radio signals near Earth's poles and could interfere with airline travel close to these regions.

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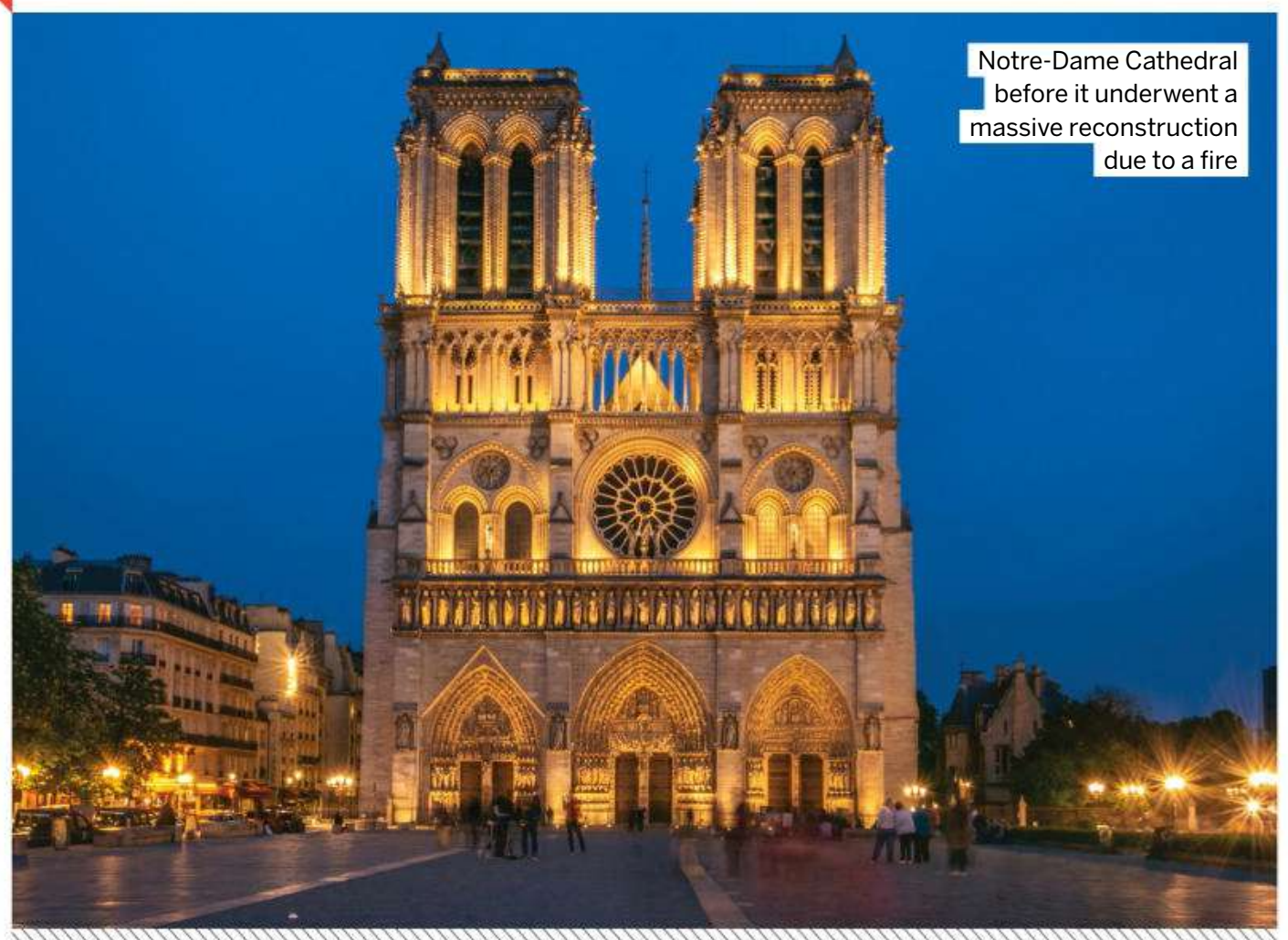


Notre-Dame Cathedral before it underwent a massive reconstruction due to a fire

HISTORY

Catastrophic fire revealed Notre-Dame's 'iron skeleton'

WORDS **JENNIFER NALEWICKI**

In 2019, a fire broke out inside Notre-Dame Cathedral in Paris, severely damaging the iconic building. However, the catastrophic fire gave researchers an opportunity to study the building's architecture like never before. A few months after the inferno was extinguished, researchers discovered that the stones used to build the Gothic-style cathedral were held together using iron staples, a technique that had never been documented before in a building from this time period.

Notre-Dame was constructed in multiple phases starting in the early 12th century and continuing for the next 300 years. "This is the first building of its kind in which we see this," said Maxime L'Héritier, a professor in the Department of History at Paris 8 University. "This shows [that the builders] at the time were trying to experiment with new forms of construction." L'Héritier and his team analysed 12 of the iron staples, which measure approximately 50 centimetres long and were part of the 'iron skeleton' holding the building together.

The iron staples offered additional reinforcements to the cathedral's stonework, including holding together the large arches in the nave of the building's towering 69-metre twin towers. Without the staples' support, this architectural feat would likely have been impossible to accomplish in 1160, when construction of the building began. "When we studied other Gothic churches of that time period, none used iron in their construction," L'Héritier said. "We believe that the staples were what enabled them to build this structure at such a terrific height."

Did you know?

Notre-Dame means 'Our Lady', referring to the Virgin Mary

Researchers radiocarbon dated the iron staples and discovered that they were used during one of the initial construction phases, "confirming that the production date of the staples was the same as the masonry, which also dated to around 1160." However, L'Héritier cautioned that it will take further analysis to know the iron's exact origins. "We're trying to figure out if it's local or more distant. There also seems to be different ore sources depending on whether the construction occurred in the 12th or 13th century. We do know that the bishop died at the end of the 12th century, so it's possible that a new ore resource was used years later. We should know more in a year or two." In the four years following the blaze, Notre-Dame has been undergoing reconstruction. It's expected to reopen to visitors in December 2024.

HISTORY

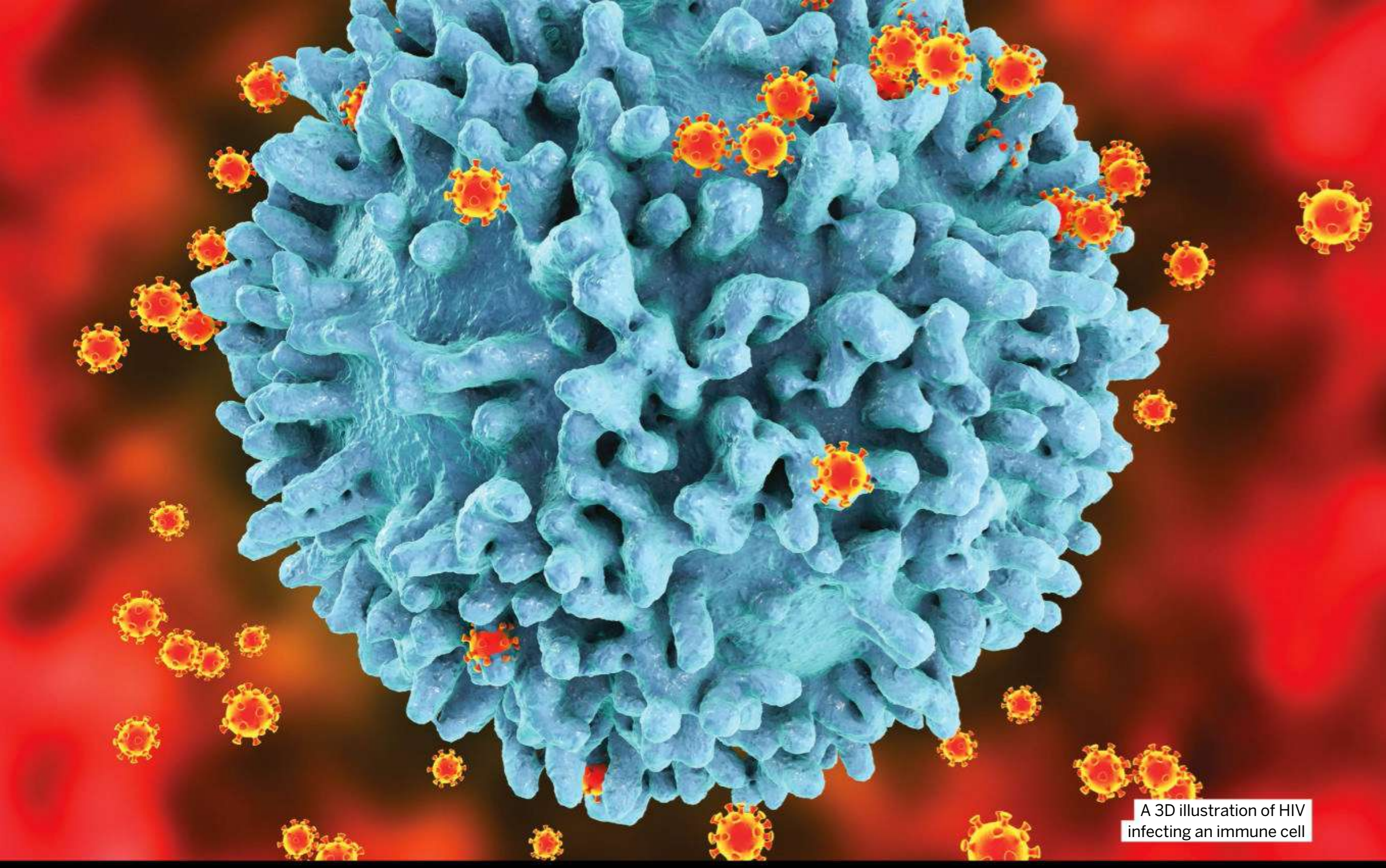
A new moai statue that 'deified ancestors' discovered

WORDS **LAURA GEGGEL**

A previously unknown moai statue, one of Easter Island's massive carved monoliths, has been found buried beneath a dried-up lakebed. Easter Island, also known as Rapa Nui, sits about 2,200 miles off the western coast of Chile and is home to nearly 8,000 people and about 1,000 moai statues. Unlike the other statues, which were found across the island, including on the slopes around Lake Rano Raraku, a volcanic crater that supplied much of the volcanic stone used to craft the moai statues, this moai was found in an unexpected place: the bottom of Lake Rano Raraku. The crater held fresh water until climate change and other factors – such as human use – caused it to dry up in recent years. In 2018 the lake water had nearly disappeared.

The moai, whose torsos are buried underground, are famous for their carved heads and 'pukao', hat-like coverings made from a soft red stone. The monoliths are enormous, too, with the largest statue, named Moai Paro, standing at ten metres tall and weighing 82 tonnes. The newfound statue, however, is smaller than most statues on the island. The Indigenous islanders of Rapa Nui built the statues in a span of about 500 years, between the 13th and 18th centuries CE.

A moai statue with the Ahu Tongariki moai in the background



A 3D illustration of HIV infecting an immune cell

HEALTH

A stem cell transplant-cured HIV patient is virus-free after five years

WORDS **NICOLETTA LANESE**

A woman known as the 'New York patient' received a stem cell transplant to cure her HIV, and now she's been virus-free and off her HIV medication for about 30 months. "We're calling this a possible cure rather than a definitive cure, waiting on a longer period of follow up," said Dr Yvonne Bryson, director of the Los Angeles-Brazil AIDS Consortium at the University of California, Los Angeles. Only a handful of people have been cured of HIV, so at this point there's no official distinction between being cured and being in long-term remission. Although the New York patient's prognosis is very good, "I think we're reluctant to say at this point whether she's cured," said Dr Deborah Persaud, the interim director of paediatric infectious diseases at Johns Hopkins University School of Medicine.

The patient received a stem cell transplant in August 2017 and stopped taking ART a little over three years later. Now she's been off the medication for roughly 2.5 years, and "right now, she's still doing very well, enjoying her life," said Dr Jingmei Hsu, director of the Cellular Therapy Laboratory at NYU Langone Health. Earlier HIV cure cases, including definitive cures in men treated in London, Berlin and Düsseldorf, and one case of long-term remission in a man treated in Los Angeles, had received stem cell transplants taken from bone marrow as a dual treatment for both cancer and HIV.

All these transplants used bone marrow stem cells from adult donors who carried two copies of a rare genetic mutation: CCR5-Δ32. This mutation alters the doorway that HIV typically uses to enter white blood cells, and thus blocks the virus from entering. After transplantation, the donor stem cells essentially take over the patient's immune system, replacing their old HIV-vulnerable cells with new HIV-resistant ones. To clear the way for the new immune cells, doctors wipe out the original immune cell population using chemotherapy or radiation therapy.

Like previous cases, the New York patient had both cancer and HIV and underwent chemotherapy prior to her transplant. However, she received stem cells taken from umbilical cord blood that contained the HIV-resistant genes. The umbilical cord blood was donated by an unrelated baby's parents at the time of delivery and later screened for the CCR5Δ32 mutation. To supplement those umbilical cord stem cells, as they were relatively few in number, the patient also received stem cells that had been donated by a relative, which helped bridge the gap as her HIV-resistant cells began to come in. Because umbilical cord blood is easier to access than adult bone marrow and more easily 'matched' between donors and recipients, such procedures could become more common in the future. However, stem cell transplants wouldn't be appropriate for patients who are HIV-positive but don't have a second serious disease, like cancer, because it involves wiping out the immune system.

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GLOBAL EYE

SPACE

ROLLS-ROYCE IS FUNDED FOR A TINY LUNAR NUCLEAR REACTOR

WORDS **JOSH DINNER**

The UK Space Agency has decided to continue funding a project by Rolls-Royce to create a small nuclear-powered reactor that could serve as a long-term energy source for future lunar bases. The new boost to Rolls-Royce's research pot follows a previous £249,000 ($305,430) study funded by the UK Space Agency in 2022. With the new funds, the company hopes to have a demonstration model for a modular microreactor ready to deliver to the Moon by 2029. The microreactor program will help develop technology that will provide power to people working on the Moon.

The continuing research will focus on three critical aspects of the microreactor: generating heat, transferring that heat and converting that heat into usable energy. "This innovative research by Rolls-Royce could lay the groundwork for powering continuous human presence on the Moon," said Paul Bate, chief executive of the UK Space Agency. There's also the matter of outfitting the microreactor to operate in the lunar environment. Currently, a majority of space travel is powered by solar energy. A nuclear power source allows for more versatility in missions and less reliance on the Sun.

Artist's illustration of a Rolls-Royce microreactor on the Moon

HEALTH

An artificial sweetener may increase the risk of heart attack and stroke

WORDS **JENNIFER NALEWICKI**

A popular zero-calorie sweetener is being linked to an increased risk of heart attack and stroke. Known as erythritol, the sugar substitute occurs naturally at low levels in some plants, like grapes and mushrooms, but is also produced industrially and added to food at higher concentrations. In particular, it's often used to sweeten low-calorie, low-carbohydrate and 'keto' products, which are typically high-fat and low-carbohydrate.

Researchers from the Cleveland Clinic in Ohio evaluated more than 4,000 Americans and Europeans who were undergoing cardiac evaluation and found that those with the highest blood concentration of the artificial sweetener were at an increased risk of experiencing a heart attack or stroke in the following three years. Notably, the majority of the participants already had some form of cardiovascular disease or exhibited risk factors for developing cardiac issues in the future, such as diabetes or high blood pressure. "People are trying to do something healthy for themselves, but inadvertently may be doing harm," Dr Stanley Hazen, a cardiologist at the Cleveland Clinic, said.

In laboratory experiments, erythritol boosted the activity of platelets – a type of blood cell that sticks together to form clots – causing clots to form at a faster rate. Similarly, in mice injected with erythritol, clots formed more quickly after injury than they did in mice injected with saline. The team also took blood samples from humans who'd had an erythritol-sweetened drink, finding that their blood levels of the sweetener peaked within hours and remained high for two days – high enough that it could potentially affect their blood clotting.

Increased clotting has the potential to cause a heart attack or stroke because blood flow becomes constricted as clots form. "Every way we looked at it, it kept showing the same signal," Hazen said. However, it's worth noting that there were some limitations to the study, particularly that many participants were more than 60 years old and already had heart disease, meaning they were already at some risk of heart attacks and stroke. While the study showed some connection between clot formation and erythritol, it did not show the compound actually caused strokes and heart attacks in humans.

"[This study is] extremely important, and it will likely trigger immediate changes in what we consume," Greg Neely, a professor of functional genomics at the University of Sydney who was not involved in the study, said. "We don't fully understand what the health consequences of industrialised food have been, and just because something is sold as 'natural' doesn't mean it is safe or good for us to consume at an industrial scale." The study authors concluded that "studies assessing the long-term safety of erythritol are warranted."

Consumption of erythritol, a popular sweetener, is being linked to a higher probability of having a heart attack or stroke

PLANET EARTH

Scientists discover an enzyme that turns air into energy

A scanning electron microscope image of a bacterium that can use atmospheric hydrogen to generate an electrical current

WORDS **BEN TURNER**

Scientists have discovered a bacterial enzyme that converts hydrogen into electricity, and they think it could be used to create a new, clean source of energy literally from thin air. The enzyme, which has been named Huc, is used by the bacterium *Mycobacterium smegmatis* to draw energy from atmospheric hydrogen, enabling it to survive in extreme, nutrient-poor environments. Now, by extracting and studying the enzyme, researchers say they have found a new energy source that could be used to power a range of small portable electrical devices."We imagine that a Huc-containing power source could power a range of small portable devices using air, including biometric sensors, environmental monitors, digital clocks and calculators or simple computers," said Rhys Grinter, a microbiologist at Monash University in Australia. "When you provide Huc with more concentrated hydrogen it produces more electrical current, which means you could use it in fuel cells to power more complex devices like smartwatches or smartphones, more portable complex computers and possibly even a car."

M. smegmatis is a nonpathogenic, fast-growing bacterium often used in the lab to study the cell wall structure of its close disease-causing relative *Mycobacterium tuberculosis*. Commonly found in soil all over the world, *M. smegmatis* has long been known to convert trace hydrogen in the air into energy; in this way, the microbe can survive in the toughest environments – including Antarctic soils, volcanic craters and the deep ocean – where little other fuel can be found. But until now, how *M. smegmatis* did this was a pervading mystery.

To investigate the chemistry behind *M. smegmatis*' shocking ability, scientists first isolated the Huc enzyme responsible for the process using chromatography. Then they investigated the enzyme's atomic structure with cryogenic electron microscopy. By beaming electrons onto a frozen sample of the Huc enzyme that was gathered from *M. smegmatis*, researchers mapped out the enzyme's atomic structure and the electrical pathways it uses to carry the electrons so that they form a current.

The team discovered that at its centre, Huc has a structure called an active site that contains charged ions of nickel and iron. Once hydrogen molecules – made up of two protons and two electrons – enter the active site, they become trapped between the nickel and iron ions and get stripped of their electrons. The enzyme then sends these electrons along in a flowing stream to generate a current. "The electrons are absorbed by Huc, specifically the nickel ion, and are transferred to the surface of Huc by a molecular wire formed by clusters of iron and sulphur ions," Grinter said. "If we immobilise Huc on an electrode, the electrons can enter an electrical circuit from the enzyme surface and generate current."

Did you know?

Hydrogen is the most abundant element on our planet

The microbe's ubiquity and ability to be easily grown could make the enzyme an ideal candidate for a power source in organic batteries. "Huc can extract energy from hydrogen in the air, which is effectively limitless," Grinter said. "The amount of electricity that can be generated from the low concentrations of hydrogen in the air will be modest. This will limit the application of Huc in this context to devices that require a small but sustained amount of power. A complementary use of Huc would be in fuel cells where a higher concentration of hydrogen is provided."

© Getty / Rolls-Royce Holdings

PLANET EARTH

Antarctica's sea ice reaches its lowest level since records began

WORDS **HARRY BAKER**

The amount of sea ice surrounding Antarctica has reached its lowest level since modern records began for the second year in a row. Sea ice is frozen seawater that floats on the ocean's surface around the planet's polar regions. It forms at much lower sustained temperatures than freshwater ice does, at around -1.8 degrees Celsius. Sea ice builds up during the winter until it reaches its maximum extent and then melts away in the spring and summer until it reaches its minimum extent.

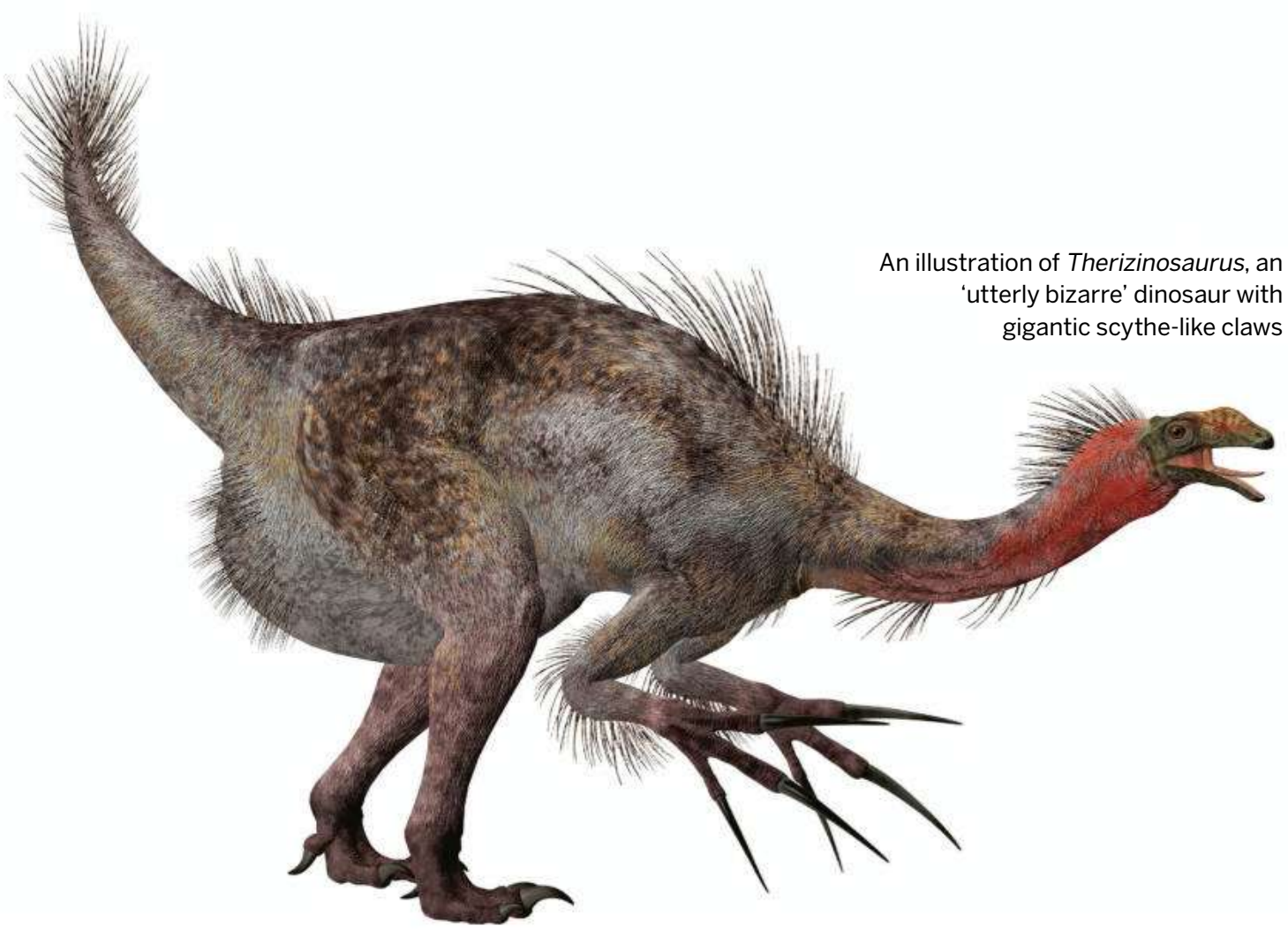
In Antarctica, where summer and winter are flipped relative to the Northern Hemisphere, sea ice normally reaches its maximum extent in September, when sea ice covers around 7 million square miles. At its minimum extent, at the end of February, historically only around 1 million square miles remains. Last year the minimum sea ice extent was less than 772,000 square miles, the lowest total since scientists began recording sea ice extent with satellites in 1979. On 21 February this year, that number had shrunk to just 691,000 square miles, which is roughly 40 per cent less than the average between 1981 and 2010.

The record-breaking minimum was expected after an extraordinarily hot January, which was the seventh-warmest since records began 174 years ago. "By the end of January, we could tell it was only a matter of time [until the record was broken]," said Will Hobbs, an Antarctic sea ice expert at the University of Tasmania and the Australian Antarctic Program Partnership. Antarctica's minimum sea ice extent will likely continue to decrease in the coming decades as global temperatures rise as a result of human-caused climate change and more multiyear ice, which acts as a seed for new ice growth, melts away.

Sea ice is crucial for polar predators, such as penguins in Antarctica and polar bears in the Arctic, which use the ice as a platform for hunting. But the sea ice also helps stabilise ice on Antarctica. "Lower sea ice extent means that ocean waves will pound the coast of the giant ice sheet, further reducing ice shelves around Antarctica," said Ted Scambos, a senior research scientist at the Cooperative Institute for Research in Environmental Sciences.

Ice shelf instability could in turn threaten massive glaciers, such as the Pine Island and Thwaites glaciers. The latter is commonly known as the Doomsday Glacier, which despite melting at a slightly slower rate than previously expected is still teetering perilously close to disaster. "If these glaciers begin a more rapid runaway loss of land ice, it could trigger a dramatic increase in sea level rise rates before the end of this century," said Julienne Stroeve, a senior research scientist at the National Snow and Ice Data Center (NSIDC). Sea ice also reflects sunlight back into space, which helps to cool Earth. Lower sea ice levels reduce the portion of light reflected, called albedo, which will further increase global warming.

Antarctica's sea ice retreated to its lowest extent since satellite records began



An illustration of *Therizinosaurus*, an 'utterly bizarre' dinosaur with gigantic scythe-like claws

ANIMALS

Bizarre dinosaur had gigantic but flimsy claws

WORDS SASCHA PARE

An 'utterly bizarre' dinosaur had claws so gigantic that they couldn't use them to fight or fend off attackers because they were too flimsy. The theropod *Therizinosaurus* lived in the Late Triassic and Cretaceous periods. Its scythe-like claws feature in the latest *Jurassic World* movie, where the beast can be seen batting away a deer and impaling the ferocious predator *Giganotosaurus*. However, the new research indicates that this depiction is inaccurate. "Movies and documentaries suggest that they used these claws like long swords to fight each other or predators," said Zichuan Qin, a doctoral student at the University of Bristol, who led the study. "But our research suggests that they cannot bear any stress, which means these animals couldn't use their claws to fight or defend themselves. The results surprised all of us, because we watched [*Jurassic World: Dominion*] last year and everyone got excited. We quickly realised, 'No, that's not true!'"

Therizinosaurs started off turkey-sized and evolved to be ten metres tall – as big as *Tyrannosaurus rex*. By the end of the Cretaceous, this "utterly bizarre" feathered dinosaur looked "kind of like a giraffe" with short legs and a "huge bottom", which it might have sat on while munching leaves, said researchers. But what made this dinosaur a real showstopper was its narrow, one-metre-long claws, the biggest of any animal ever recorded. "There's been a lot of argument about what these claws were for, partly because they're so large and partly because they're attached to an animal whose other features suggest it was a herbivore – their skulls and their teeth suggest they were plant eaters," said Paul Barrett, a palaeobiologist at the Natural History Museum in London. These disproportionate claws were so weak that they couldn't even hook and pull down branches.

The researchers used detailed scans of fossils to make 3D computer models of the claws, which they tested for different mechanical functions, such as digging, pulling and piercing.

But why did Therizinosaurus evolve seemingly useless gigantic claws? The researchers suggested that males showed off their long claws to attract females, much like peacocks unfold their tails to impress potential mates. "We conclude they were largely for display," said Mike Benton, a professor of vertebrate palaeontology at the University of Bristol. "Therizinosaus may have flashed and clacked their long claws as a means to scare others or to impress females."

The researchers presented a convincing case ruling out the use of these flimsy claws for fighting. However, "they might have had some minor role in food gathering," Benton added. "But very often in evolution, these very weird and elaborate structures that look useless generally come down to display and who gets to mate with who."

Did you know?

***Therizinosaurus cheloniformis* is the only known species of its genus**

SPACE

NASA selects Firefly Aerospace for Moon mission

WORDS ANDREW JONES

NASA has selected Firefly Aerospace to land payloads on the Moon and send another into orbit to provide communications with the lunar far side. The mission will use Texas-based Firefly Aerospace's robotic Blue Ghost lander to safely deliver two payloads to the far side of the Moon, which permanently faces away from Earth. The launch will first send the European Space Agency's Lunar Pathfinder communications and navigation satellite into an elliptical orbit around the Moon to relay signals between Earth and the payloads on the surface.

NASA announced on 14 March that it had awarded Firefly Aerospace an approximately £91 million ($112 million) contract as part of the Commercial Lunar Payload Services (CLPS) program. The initiative is part of the agency's Artemis program. "NASA continues to look at ways to learn more about our universe," said Nicola Fox, associate administrator for the Science Mission Directorate at NASA. "Going to the lunar far side will help scientists understand some of the fundamental physics processes that occurred during the early evolution of the universe."

Illustration of the Blue Ghost transfer vehicle deploying the European Space Agency's Lunar Pathfinder satellite

© Getty / Firefly Aerospace

WISH LIST

The latest tech for FUN FOOD

DASH MINI WAFFLE MAKERS

WWW.BYDASH.COM FROM $9.99 (APPROX. £8.20)

Turn waffles into Easter eggs, love hearts, flowers, skulls and much more with the Mini Waffle range by Dash. These cute kitchen additions make breakfast or dessert just that little more fun thanks to their playful designs. Dash Mini Waffle Makers are compact and easy to store at only around ten centimetres in diameter. The non-stick surface also means you can pop out your waffle creations with ease. The compact design of this waffle maker also makes it a great travel companion for caravan breaks or student halls. Although great for making the perfect waffle, these machines can also handle different recipes, such as cookie dough, chaffles and homemade hash browns.

BANANA LOCA

WWW.BANANALOCA.COM $28.99 (APPROX. £23.75)

A banana split can be great, but thanks to the Banana Loca, you can now put all your favourite toppings inside the fruit. Whether its peanut butter, chocolate, honey or jam, the Banana Loca lets you core a banana and then inject it with flavour, all while still in the peel. Once the Banana Loca is inserted into a banana – straighter bananas work better than curved ones – your chosen filling is pumped through a tube and filled along the full length of the unpeeled fruit. This means you'll get a hit of peanut butter, Nutella or honey with every bite. This gadget is a great way to get your children excited about fruit and a creative way to get them thinking about different flavour combinations.

STAR WARS R2-D2 POPCORN MAKER

WWW.UNCANNYBRANDS.COM

$99.99 (APPROX. £81.85)

Uncanny Brands is known for its brilliant gadgets that pay homage to a whole host of films and TV shows, but this popcorn maker is out of this world. The R2-D2 popcorn maker lets you turn corn kernels into delicious popcorn in minutes, which you can serve in a bowl made from R2's head. There's no oil needed in this maker because this high-powered popcorn machine uses only hot air to pop corn. R2-D2 also comes with a measuring cup to prevent overfilling and removable parts for easy cleaning. This popcorn maker would be a great addition to a *Star Wars* watch party, and thanks to the incredible amount of detail in its design, it'll feel like you've got the real robotic droid sitting alongside you.

POLAROID CANDYPLAY 3D PEN

WWW.POLAROID3D.COM

£34.95 (APPROX. $42.75)

Combining art and confectionery, the CandyPlay Pen by Polaroid allows you to make unique sweet creations. Simply load a sugar-free and vegan candy cartridge into the pen and in minutes it will be heated into a viscous candy ink to draw and sculpt whatever your imagination can conjure up at the touch of a button. There are six cartridge flavours to choose from: strawberry, orange, cola, apple, grape and lemon. There's no limit on what two or three-dimensional treats to make, but if you're struggling to find inspiration, Polaroid also provides a wide variety of fun stencils for you to use and enjoy.

YONANAS FROZEN DESSERT MAKER

WWW.YONANAS.COM £59.95 / $49.99

Frozen desserts are often packed with added sugars, fats and dairy. The Yonanas frozen dessert maker supplies all the enjoyment of eating a tasty dessert without the need for heaps of unhealthy ingredients. In fact, all it needs is frozen fruit. In the same way you might use frozen fruit in a blender to make a smoothie, this handy gadget takes things a step further and not only breaks those fruit up, but turns them into a velvety, creamy dessert. From parfaits to sorbets, the Yonanas frozen dessert maker comes with a 36-recipe cookbook to get you started. The chute assembly, plunger and blade are dishwasher-safe for easy cleaning.

PAN-N-ICE ROLL PLATE

WWW.PAN-N-ICE.CO.UK

£49.99 (APPROX. $61.10)

The Pan-n-Ice roll plate lets you roll your own delicious ice cream creations at home. To prepare the Pan-n-Ice roll plate, simply place it in a freezer at a temperature of -22 degrees Celsius and freeze it for 24 hours before use. Then grab your ice cream ingredients, either shop-bought or one of the Pan-n-Ice pre-made mixes, and pour over the ice plate. Using the child-friendly plastic spatulas, chop, shape and mix everything together before rolling it into finished ice cream rolls. You can reuse the Pan-n-Ice over and over again and try out countless flavour combinations. This gadget is great entertainment for children to enjoy all year round, especially on a hot summer's day.

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DID YOU KNOW? 92 per cent of the buildings in Hiroshima were destroyed in the 1945 nuclear strike

NUCLEAR EXPLOSIONS

The explosive science behind the biggest human-made blasts on Earth

WORDS **SCOTT DUTFIELD**

Nuclear explosions are the biggest of the big, the most energetic and the cause of some of the most catastrophic calamities in recorded history. The incendiary force of nuclear technology is unrivalled by any other form of human-made explosive. Destructive methods such as trinitrotoluene, better known as TNT, create violent outbursts as a result of chemical reactions between combustible elements, such as carbon and oxygen. Nuclear explosions, on the other hand, occur at an atomic rather than a molecular level.

The term 'nuclear' refers to the nucleus, or centre, of an atom, which is made up of particles called protons and neutrons. Different elements have different atomic structures, with some having more or fewer particles in their nucleus. When the number of protons and neutrons in the atoms of an element are balanced, they are considered stable. However, for some elements, the nuclear weighing scales are unbalanced. As part of nature's attempt to balance the scales, atoms of radioactive elements, such as uranium, expel extra protons and neutrons in a process known as radioactive decay. The rate at which an element sheds these particles is referred to as radioactivity.

Did you know?

Nine countries have either nuclear fission or fusion weapons

The road to understanding the explosive potential of nuclear energy began in the late 1780s, when a German chemist named Martin Klaproth discovered uranium. Since then, scientists have uncovered its physics and chemistry, including Pierre and Marie Curies' discovery of uranium's radioactivity in 1896, Lise Meitner and Otto Frischs' work on splitting the atom in the early 1900s and Ernest Rutherford's famous fusion experiments in 1934. Over a century's worth of research has uncovered that the explosive power of nuclear energy comes in two forms: fission and fusion. Although both can lead to immensely powerful explosions, they work in different ways.

A nuclear explosion by way of fission occurs when heavy radioactive elements such as uranium or plutonium are bombarded with a subatomic particle called a neutron. This bombardment causes the element's atoms to split, releasing energy and more neutrons as a result. A fission chain reaction in which more neutrons bombard more atoms culminates as a massive explosion, which can either be exploited for generating energy or used in warfare – an atomic bomb.

Only two nuclear fission bombs have ever been deployed against an enemy during warfare. A bomb known as 'Little Boy' was

© Alamy

dropped on the Japanese city of Hiroshima in 1945 and used less than a kilogram of uranium-235 to deliver an explosion equivalent to around 15,000 tonnes of TNT. A second attack occurred the same year, trialling a new implosion fission bomb called 'Fat Man' that used a kilogram of plutonium-239 to release the equivalent of 21,000 tonnes of TNT over the Japanese city of Nagasaki.

Nuclear fusion, on the other hand, works in a very different way to a fission reaction. Rather than splitting an atom in two, fusion forces two atoms of a light element, such as hydrogen, together to form a new element, such as helium. The fusion of these two atoms also releases enormous amounts of energy. Of the nine nuclear-capable countries in the world, six are packing weapons that exploit the immense energy released from nuclear fusion. A hydrogen bomb, also referred to as a thermonuclear weapon, converts hydrogen into helium by way of nuclear fusion to release massive amounts of explosive energy. The first nuclear fusion explosion occurred in 1952 on the Enewetak Atoll, part of the Marshall Islands in the Pacific Ocean. Known as a hydrogen bomb, this unprecedented device unleashed an explosion equal to over ten megatonnes of TNT, the heat of which could be felt around 30 miles away.

Since World War II, nuclear explosions have been limited to tests. Nuclear tests are delivered in one of four ways – atmospheric,

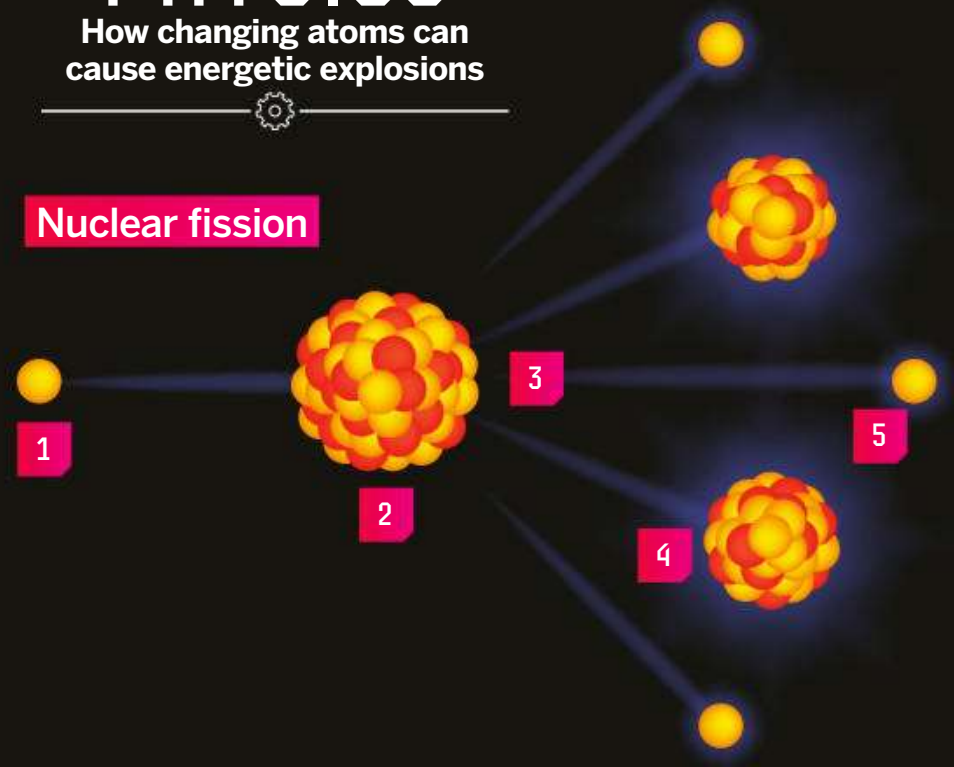
Did you know?

The Trinity test could be seen from 200 miles away

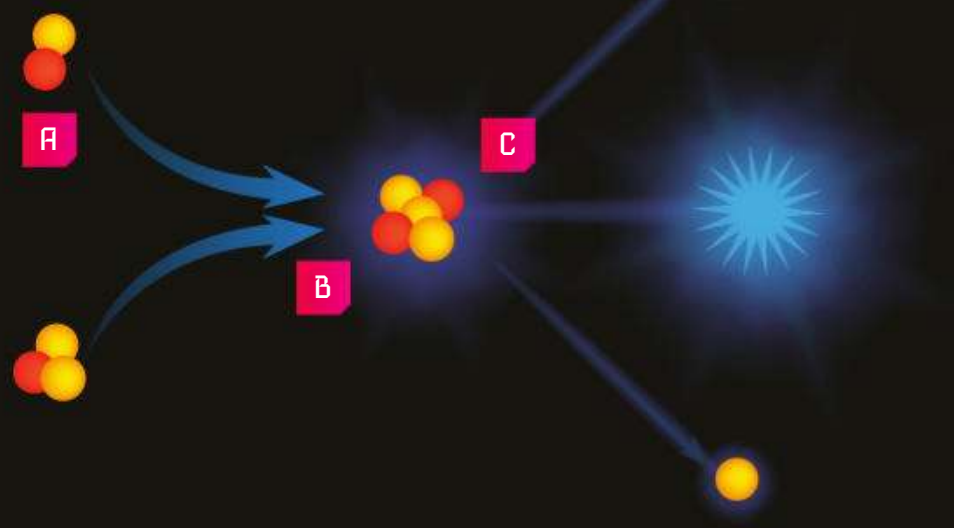
NUCLEAR PHYSICS

How changing atoms can cause energetic explosions

Nuclear fission



Nuclear fusion



1 FREE NEUTRON
A free-moving neutron is the catalyst.

2 URANIUM-235
A radioactive isotope of uranium is used in fission reactions because, unlike other elements, it's easily split by a neutron.

3 ENERGY
The energy released is mostly kinetic, which is transferred into heat.

4 LIGHT ELEMENT
When uranium-235 is bombarded with neutrons, it splits into lighter elements called krypton and barium.

5 CHAIN REACTION
Once one uranium atom is split, the resulting energy and shed neutrons trigger fission reactions in surrounding uranium atoms.

A FAMILY MEMBER
Isotopes of hydrogen called deuterium and tritium are commonly used in nuclear fusion reactions.

B ENERGY
When hydrogen isotopes bind together, they release a large amount of energy.

C HELIUM
When deuterium and tritium bind, they form a helium atom and release a spare neutron.

TYPES OF NUCLEAR WARHEADS

TRIGGER

In a similar way to how a trigger fires the bullet of a gun, a fission bomb detonates following the release of an internal explosion that propels a bullet of radioactive material, typically a marble of uranium-235, into a subcritical mass of the same material. The result causes a fission reaction and an explosion.

IMPLOSION

Rather than firing two sources at one another, an implosion bomb uses a central subcritical radioactive source and encases it in highly explosive material. By detonating that explosive material, a shock wave is created that compresses the radioactive source to the point that a fission reaction occurs.

CHAIN REACTION

Fusion bombs work in two stages. Firstly, an internal fission bomb detonates, causing the release of extreme heat and X-ray radiation. The heat and radiation created from the fission bomb are focused onto a fusion fuel source, which is compressed until a fusion reaction occurs and the bomb explodes.

DID YOU KNOW? The most recent nuclear test was carried out in 2017 by North Korea

MUSHROOM CLOUD

How explosive heat and a cold atmosphere converge to form this distinctive cloud shape

3 COLLIDING WITH COOL AIR
When the fireball rises and meets cool air, a phenomenon known as Kelvin-Helmholtz instability causes billowing clouds to form the mushroom.

4 BIG MUSHROOM
Mushroom clouds can reach great heights. Within ten minutes, the Tsar Bomba's cloud grew 42 miles tall and 60 miles wide.

5 TOP RING
The top of the mushroom cloud is shaped almost like a doughnut, with a vortex circulating through the middle of the ring.

2 HEAT RISES
The fireball of hot air rises quickly, creating a vacuum that picks up debris and dust, forming the stem of the mushroom cloud.

6 CONDENSATION CLOUD
A low-pressure wave following a blast condenses atmospheric water into rings around the explosion called Wilson clouds.

1 FIREBALL
Following an explosion, the emitted X-rays heat up and ionise the surrounding air, creating a bubble of hot gas called a fireball.

A sample of trinitite found at the site of the Trinity test

FIRST EXPLOSION

The first time a nuclear explosion was carried out was on 16 July 1945 in the New Mexico desert, at the Alamogordo Bombing Range. The proof of concept, now known as the Trinity test, showcased the atomic workings of the Manhattan Project, a research undertaking by the US to produce the first nuclear weapon during World War II. The bomb used in the Trinity test was called Gadget; it was an implosion bomb that used compressed radioactive plutonium to generate a nuclear fission explosion. Gadget was dropped from a 30-metre steel tower over the desert and released an explosion of 18.6 kilotonnes – equal to 19,000 tonnes of TNT – on impact. The explosion vaporised the steel tower and turned the soil beneath into a glass-like material, now known as trinitite.

A view of the first 0.025 seconds following the first-ever nuclear test, Trinity

©XXXX

high-altitude, underground or underwater – and have typically been executed in remote or uninhabited locations. The effects following a nuclear explosion are twofold: initial destruction and long-term radiation. At the heart of a nuclear explosion, temperatures reach millions of degrees Celsius, similar to the temperatures found in the interior of the Sun. In an explosion comparable to Hiroshima, around 50 per cent of people standing within the first two miles of ground zero would be vaporised in the initial blast. Those in buildings immediately surrounding this zone would likely be killed indirectly by a subsequent blast wave causing falling debris and destruction. An electromagnetic pulse typically follows a nuclear blast, which can damage electronics miles away from the detonation.

The longest lasting effect of a nuclear blast is radioactive fallout. This is when particles of dust or metal are pulled thousands of metres into the atmosphere during a nuclear explosion. Following the initial fireball, when these airborne particles cool down, radioactive atoms bind to them and make them radioactive. These particles now emit ionising radiation that can strip atoms of their electrons, including the atoms that make up the cells in an organism's body. Damage to cells by way of ionising radiation leads to DNA mutations and cellular destruction along with the development of cancers, and in high doses, death. Snow and rain can reduce the longevity of fallout in the atmosphere and bring it down to ground level, but strong winds can disrupt and extend the distribution of fallout.

But what can you do in the event of a nuclear explosion? Although nuclear attacks remain unlikely despite current world conflicts, governments around the world each have their own set of instructions for their citizens to follow in the event of a nuclear attack. However, there are some general safety precautions to consider when faced with exposure to a blast. Finding shelter is the most important action to take in the event of an explosion. To avoid radioactive fallout, people should immediately move inside a building, ideally with an underground basement or bunker. Windows and doors should be sealed and any air-filtration system should be initially turned off until the fallout cloud has passed. If a person is caught outside during the blast, removing their clothing upon finding shelter can restrict the spread of any radioactive material. Similarly, taking a shower helps remove any radioactive material from the skin. However, hair conditioners can bind to radioactive material, and should therefore be avoided.

INSIDE A BUNKER

What might you expect to see beneath the ground in a fallout shelter?

Did you know?

Almost 200,000 people were killed at Hiroshima and Nagasaki

11 OVERPRESSURE VALVE
If the air pressure is greater inside than outside the bunker, the overpressure valve opens to release some pressure.

1 UNDERGROUND
Bunkers typically sit around three metres below the surface, with packed soil separating the roof of the bunker from the surface.

2 MATERIALS
Robust materials are used to build shelters, the walls of which are reinforced by steel rebars.

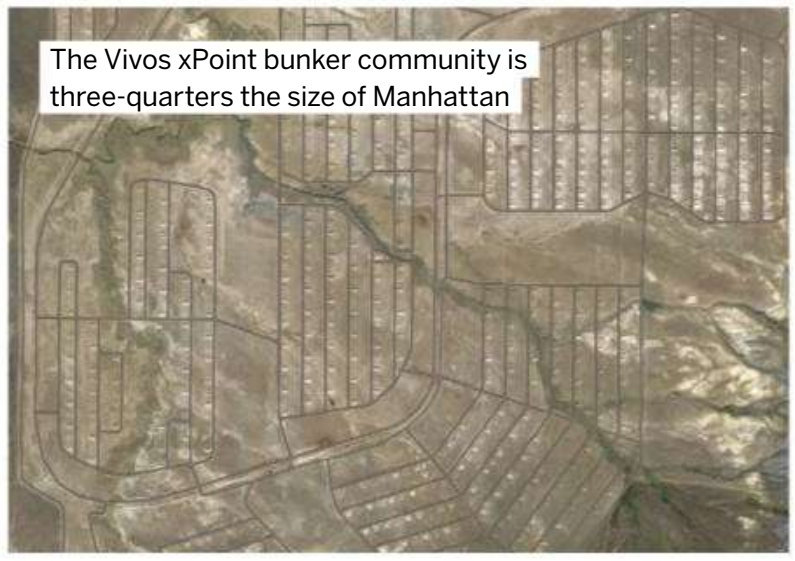
6 AIR FILTRATION
Maintaining clean and safe internal air is paramount when living in a bunker.

3 WATER
A person needs around two litres of water a day to survive. In a bunker this can come from bottled water, inbuilt groundwater wells or water filtration systems.

DID YOU KNOW? The first White House bunker was built during World War II for President Franklin D. Roosevelt

THE BIGGEST BUNKER

The largest bunker community in the world is known as Vivos xPoint and can be found in the Black Hills of South Dakota. The underground behemoth consists of a network of 575 individual concrete bunker units that collectively span 18 square miles. Each unit forming part of the community has an area around 204 square metres, and together these units can house more than 5,000 people. The site of the Vivos xPoint was previously used as a US Army ammunition depot that was built to bear the force of a nuclear explosion. According to Vivos, each bunker can withstand a 20-megatonne explosion within just a few miles. Along with residential space, there's also a restaurant, bar, gym and medical centre for bunker inhabitants to enjoy during their time underground. Ownership of these bunkers isn't cheap – they have a price tag of around £38,000 ($45,000) each.



The Vivos xPoint bunker community is three-quarters the size of Manhattan

7 GEIGER COUNTER
A geiger counter sensor peeking out of the surface can inform the bunker inhabitants about surface radiation.

10 BLAST VALVE
This valve is used to maintain the air pressure within the bunker during a shock wave generated by a nuclear explosion.

5 MULTIPLE EXITS
Multiple ways to exit a bunker prevent its inhabitants from being trapped should one exit be damaged or become inaccessible.

4 FOOD SUPPLY
Bunkers should be shocked with plenty of non-perishable foods, such as honey, uncooked rice and canned foods.

8 POWER SUPPLY
Bunkers are often equipped with a remote electricity generator in the event of a mains source being disconnected.

9 AQUAPONICS
Fresh vegetables may be scarce following a nuclear explosion, along with unsuitable growing soil on the surface. An aquaponics unit uses fish tanks to supply nutrients to growing vegetables above.

© Google / Illustration by Nicholas Forder

SPECIAL

THE TEN BIGGEST NUCLEAR EXPLOSIONS

The largest human-made nuclear detonations throughout history

Castle Romeo was carried out on a barge in the crater left by Castle Bravo

IVY MIKE

1952 / US
Location:
Enewetak Atoll
Yield:
10.4 megatonnes
Mushroom cloud height:
26 miles

This was the first nuclear fusion bomb tested by the United States. Ivy Mike yielded an explosive force around 690 times that of the Hiroshima bomb over Enewetak Atoll in the Pacific Marshall Islands. The bomb exploded using liquid deuterium as a fusion fuel, which was superheated by an internal fission bomb.

CASTLE BRAVO

1954 / US
Location:
Bikini Atoll
Yield:
15 megatonnes
Mushroom cloud height:
25 miles

The first in a series of US nuclear tests under Operation Castle, the Bravo explosion unleashed around two-and-a-half times the amount of explosive force that was anticipated. The fallout spread 7,000 square miles over the Marshall Islands and across the Pacific.

CASTLE ROMEO

1954 / US
Location:
Bikini Atoll
Yield:
11 megatonnes
Mushroom cloud height:
18 miles

This was the second test of Operation Castle. The detonation occurred on a barge off Bikini Atoll just a few months after the Castle Bravo test. High winds at the time of the initial blast may have caused radioactive fallout to spread throughout the Marshall Islands and out to sea for around a month.

CASTLE YANKEE

1954 / US
Location:
Bikini Atoll
Yield:
13.5 megatonnes
Mushroom cloud height:
35 miles

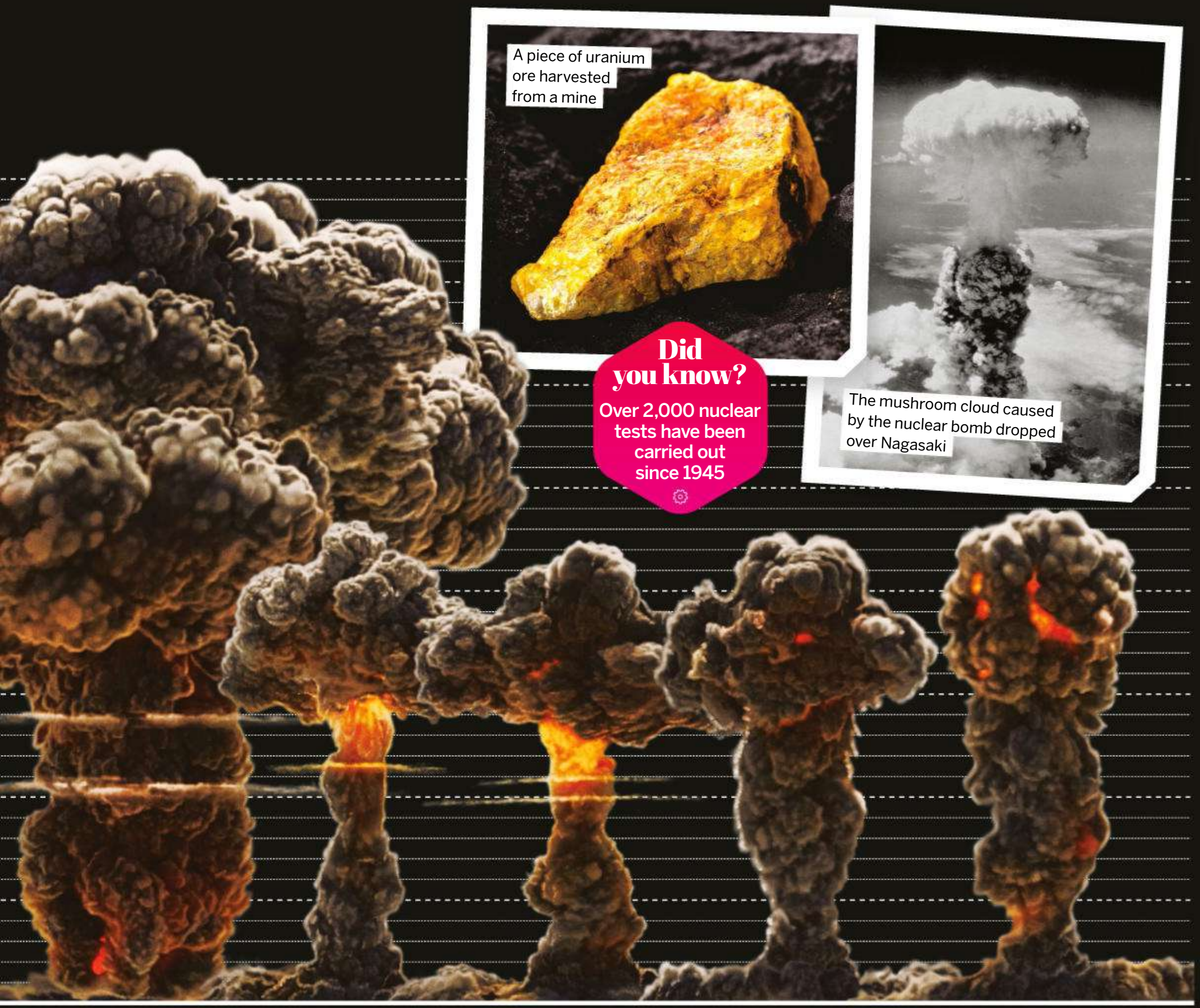
This was the fifth instalment of Operation Castle. The fallout of the explosion spread rapidly due to strong winds. It reportedly reached Mexico City four days following the explosion, more than 7,000 miles from the detonation.

TEST 123

1961 / USSR
Location:
Novaya Zemlya
Yield:
12.5 megatonnes
Airburst height:
2.1 miles

Just a week before the Soviet Union dropped the Tsar Bomba, this test detonation exploded with a force of around 830 times greater than the Hiroshima bomb. Everything within the first two square miles of this tests' explosion was incinerated.

DID YOU KNOW? There are 400 commercial nuclear reactors supplying energy to 31 countries worldwide


A piece of uranium ore harvested from a mine
The mushroom cloud caused by the nuclear bomb dropped over Nagasaki
Did you know?
Over 2,000 nuclear tests have been carried out since 1945
40
30
20
10
Miles

TSAR BOMBA

1961 / USSR
Location:
Novaya Zemlya
Yield:
50 megatonnes
Mushroom cloud height:
40 miles

Around 3,300 times more powerful than the bomb dropped over Hiroshima, Tsar Bomba, meaning 'King of Bombs', was a hydrogen bomb detonated by the Soviets over Novaya Zemlya in the Arctic Ocean. The fireball spanned six miles wide and was so bright that its light could be seen 620 miles away.

TEST 147

1962 / USSR
Location:
Novaya Zemlya
Yield:
21.1 megatonnes
Airburst height:
2.2 miles

The USSR carried out 79 nuclear tests during 1962, including Test 147, the third-biggest nuclear blast in history.

TEST 173

1962 / USSR
Location:
Novaya Zemlya
Yield:
19.1 megatonnes
Airburst height:
2.5 miles

Like all of the USSR's 1962 tests, not much is known about this detonation, only that it was carried out atmospherically rather than on the surface or underground.

TEST 174

1962 / USSR
Location:
Novaya Zemlya
Yield:
20 megatonnes
Airburst height:
2.4 miles

The fifth-biggest nuclear test in history was also conducted in 1962 by the USSR on a remote island off the northeast coast of modern-day Russia.

TEST 219

1962 / USSR
Location:
Novaya Zemlya
Yield:
24.2 megatonnes
Airburst height:
2.3 miles

Detonated over the same archipelago as Tsar Bomba, this nuclear explosion was detonated within the atmosphere around 2.3 miles above sea level. The bomb was released into the air and then shot by an intercontinental ballistic missile (ICBM) to detonate it.

© Illustrations by Nicholas Forder

NUKES BY NUMBERS

UNITED STATES
First test: 16 July 1945
Most recent: 23 September 1992
Total tests: 1,054

FRANCE
First test: 13 February 1960
Most recent: 27 January 1996
Total tests: 210

UNITED KINGDOM
First test: 3 October 1952
Most recent: 26 November 1991
Total tests: 45

USSR
First test: 29 August 1949
Most recent: 24 October 1990
Total tests: 727

INDIA
First test: 18 May 1974
Most recent: 13 May 1998
Total tests: 3

PAKISTAN
First test: 28 May 1998
Most recent: 30 May 1998
Total tests: 2

CHINA
First test: 16 October 1964
Most recent: 29 July 1996
Total tests: 47

NORTH KOREA
First test: 9 October 2006
Most recent: 3 September 2017
Total tests: 6

NUCLEAR-CAPABLE COUNTRIES

100 MILLION DEGREES CELSIUS

At its peak, a one-megatonne bomb is hotter than the core of Sun, which is 15 million degrees Celsius

92 U Uranium 238.03

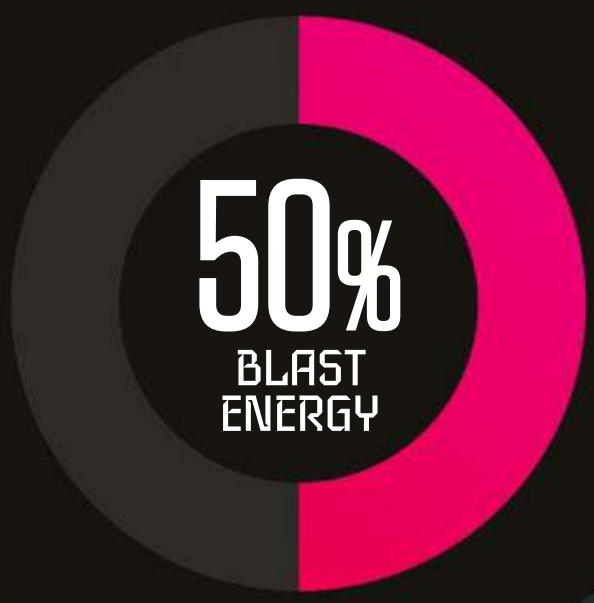
85%

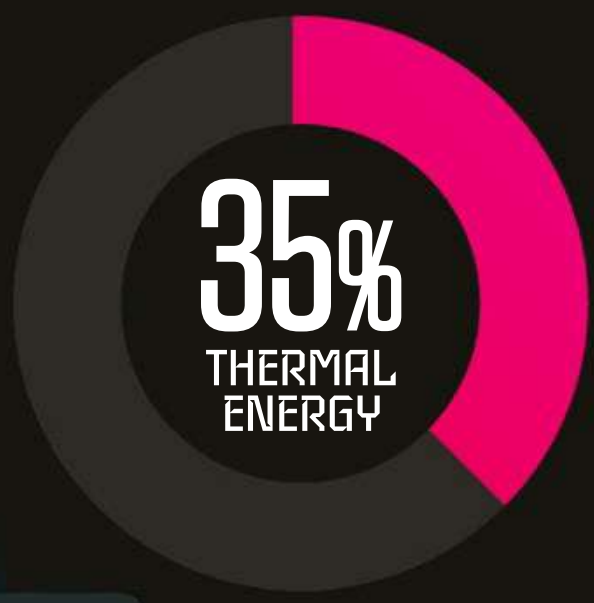
Most of the world's uranium is produced in six countries: Kazakhstan, Canada, Australia, Namibia, Niger and Russia

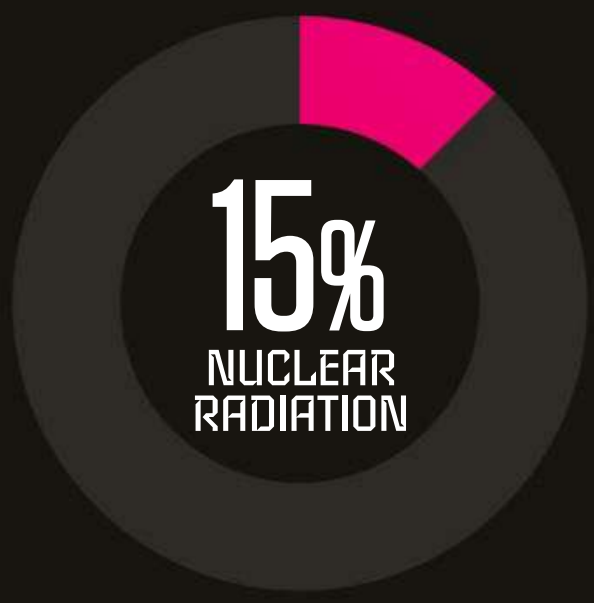
Turkey, Italy, Belgium, Germany and the Netherlands all host United States nuclear weapons

DID YOU KNOW? Tsar Bomba is the most powerful nuclear blast in history

ENERGY BREAKDOWN OF A NUCLEAR EXPLOSION

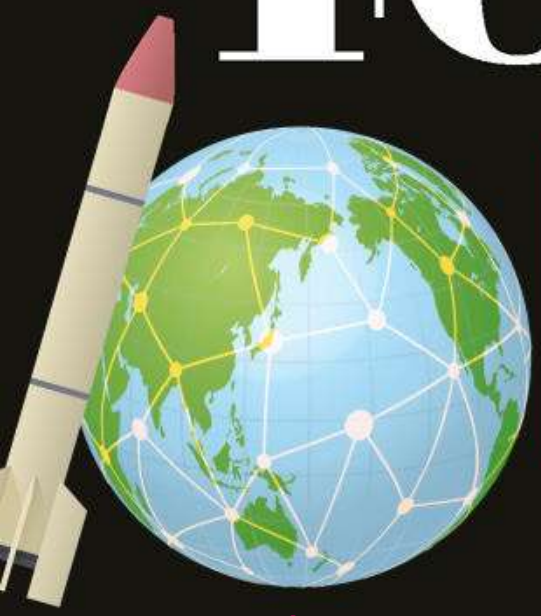






40

The number of nuclear warheads on UK submarines



4.5 BILLION YEARS

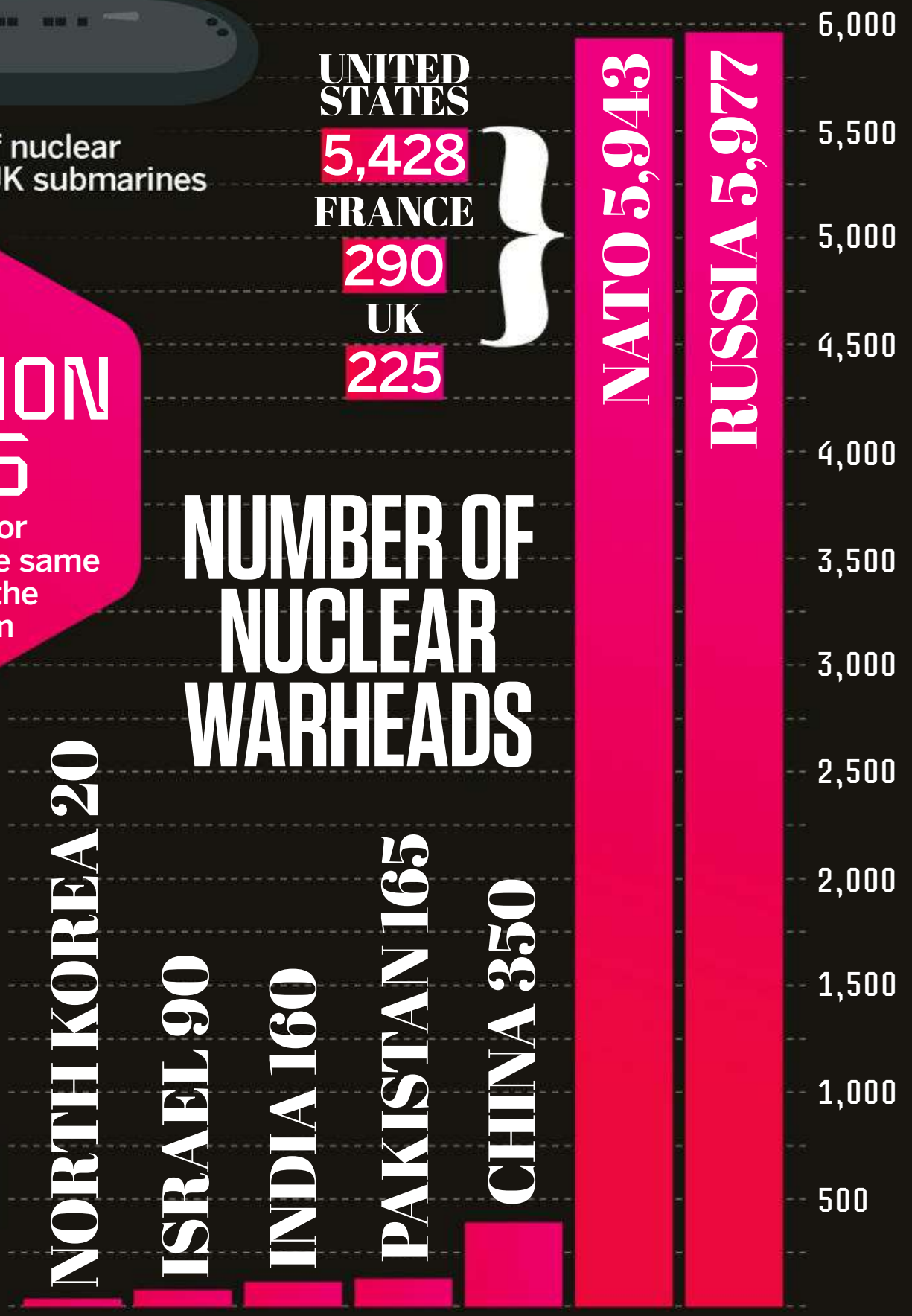
The half-life for uranium-238 is the same as the age of the Solar System

Five nations have nuclear missiles with ranges that can reach any place on Earth

191

Most countries have signed a treaty to prevent the spread of nuclear weapons

NUMBER OF NUCLEAR WARHEADS



© Getty

What are the CROWN JEWELS WORTH?

Discover the history of the precious artefacts worn by Britain's monarchs

WORDS **AILSA HARVEY**

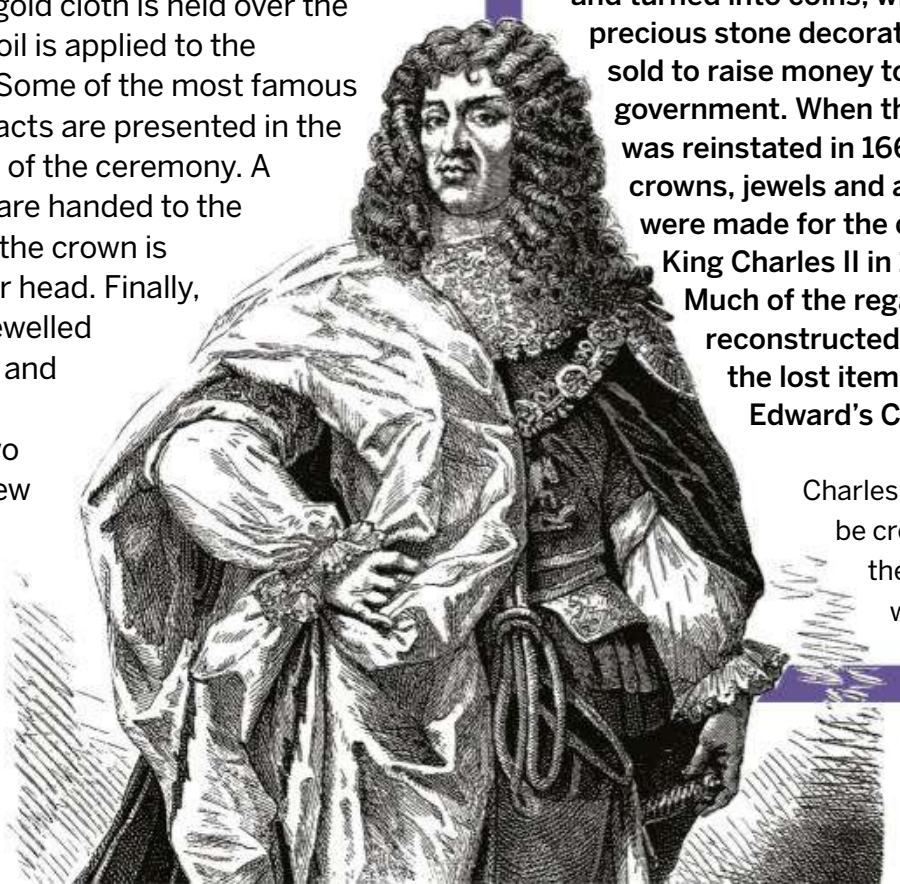
In May 2023, Britain will ceremonially announce its new regal leader, King Charles III. This event is known as a coronation, which comes from the Latin word 'corona', meaning crown. The central act of a coronation is the crowning of a new monarch, but there are other specific rituals that traditionally surround this event. There hasn't been a coronation for 70 years, since Queen Elizabeth II had the crown placed on her head in 1953.

Coronation ceremonies take place in Westminster Abbey, where they have done for over 900 years. During these services, there are several stages. These include the recognition, oath, anointing, investiture and enthronement. In each part of the coronation, ancient objects are used, presented and worn in keeping with the traditions of the monarchy. The recognition stage is the first event to take place. This is where the new monarch is presented to those who have gathered. The Archbishop of Canterbury leads the coronation, since they have a higher ranking than most individuals in the royal family, and begins by introducing the king or queen. As they do so, the congregation calls out "god save the king!" or "god save the queen!".

The coronation oath is one of the most important elements of the ceremony, as this is when the new monarch agrees to take on the responsibility of their role. During the oath-taking, they promise to uphold the law and the Church of England. After the oath is the anointing stage. It's traditional that the coronation robe is removed and the new monarch sits on the coronation chair. To conceal this part of the ceremony from the congregation, a gold cloth is held over the chair, while holy oil is applied to the monarch's skin. Some of the most famous coronation artefacts are presented in the investiture stage of the ceremony. A sceptre and orb are handed to the monarch before the crown is placed upon their head. Finally, carrying the bejewelled golden artefacts and wearing a crown weighing over two kilograms, the new monarch walks to the throne to take their seat as the new sovereign.

MELTED DOWN

In 1649 the monarchy was temporarily abolished as England became a republic. The new government melted down many of the royal jewels and artefacts. The gold frames were melted in the Tower of London's mint and turned into coins, while the precious stone decorations were sold to raise money to fund the government. When the monarchy was reinstated in 1660, new crowns, jewels and artefacts were made for the coronation of King Charles II in 1661. Much of the regalia was reconstructed to look like the lost items, such as St Edward's Crown.



Charles II was first to be crowned after the monarchy was reinstated

DID YOU KNOW? Coronations have taken place in Westminster Abbey since 1066

THE OLDEST ARTEFACT

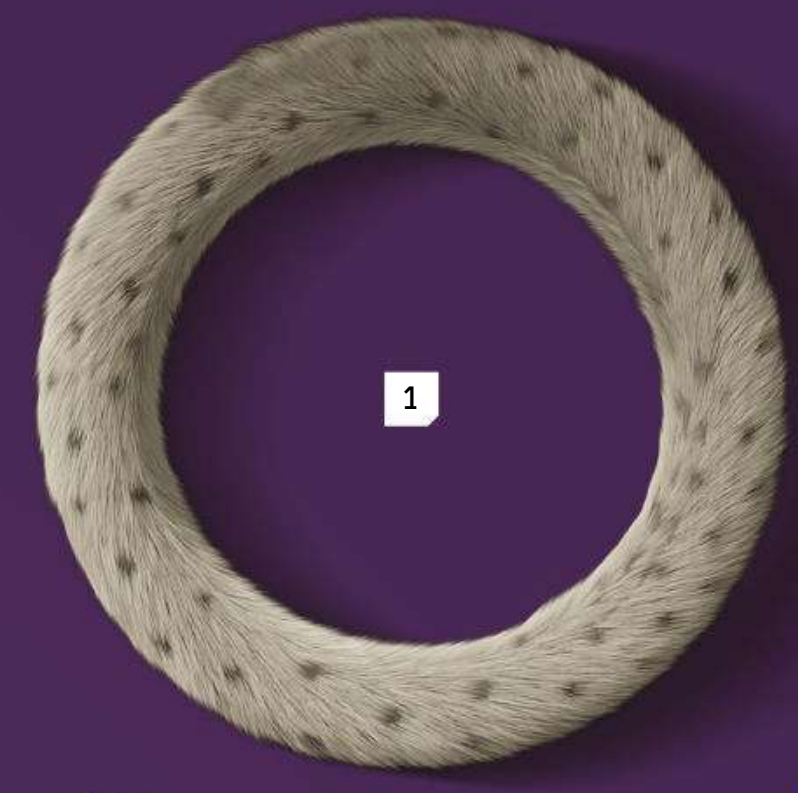
Of all the crown jewels, the Coronation Spoon is the sole survivor from the 12th century. While the original crown jewels were lost and destroyed during the 1600s, the spoon was saved as it was bought by Charles I's wardrobe servant. The silver spoon is gilded with a layer of gold and engraved with acanthus leaf designs, which symbolise rebirth and immortality. When it was first created, historians believe the utensil was used to mix water and wine. However, it was later used as an ornament for coronation ceremonies, as it continues to be today. The spoon is used by the Archbishop of Canterbury to apply holy oil to the hands, head and breast of the new monarch – a practice that once signified the divinity of the new leader. Today, kings and queens don't have the same divine rights as they did historically, because claiming that they had authoritative rights from their god prevented individuals from being held accountable for their actions. In modern coronation ceremonies, the oil is still used to confirm the monarch's new role. It is blessed in Jerusalem before it is considered sacred.

The anointing oil is poured from a golden flask, called an ampulla, onto the Coronation Spoon

Did you know?

The Coronation Spoon was described as 'ancient' in 1349

© Getty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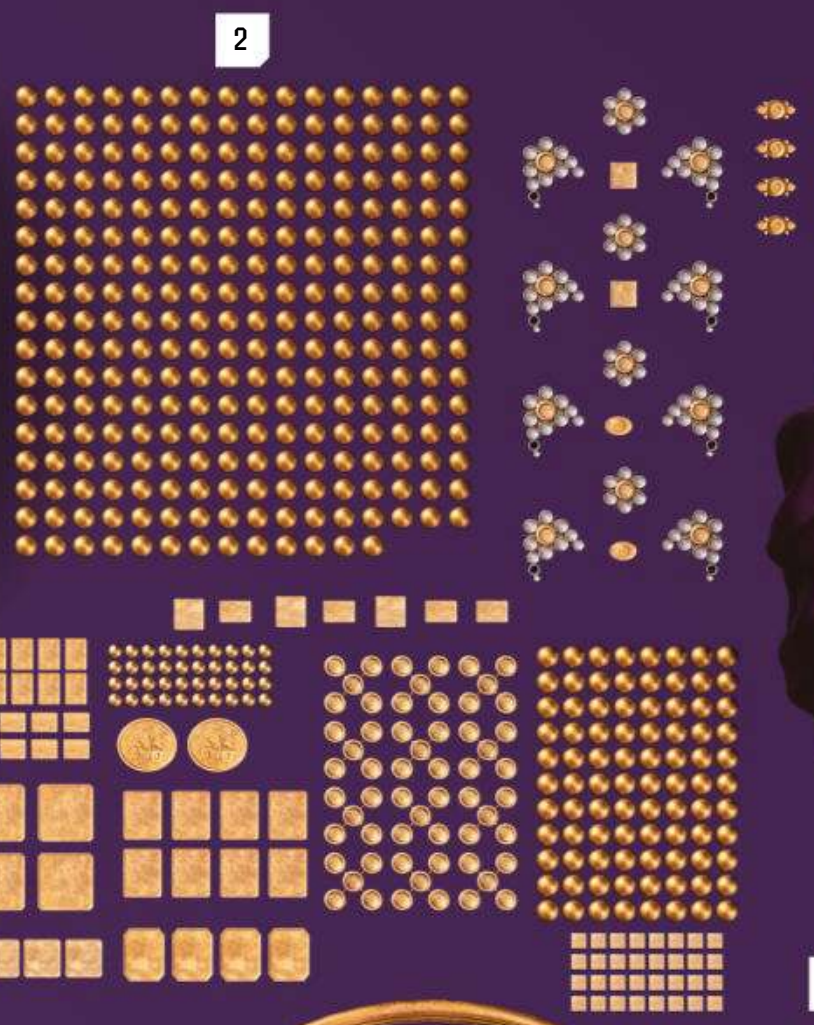
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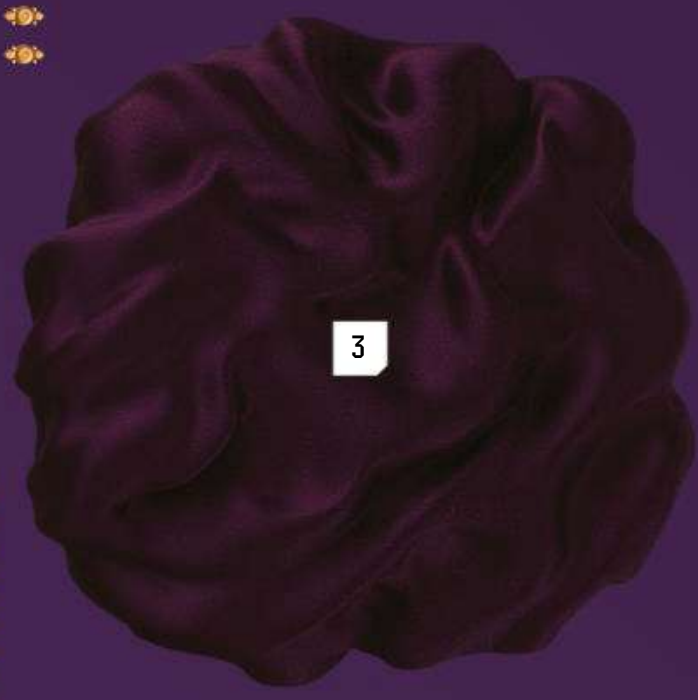
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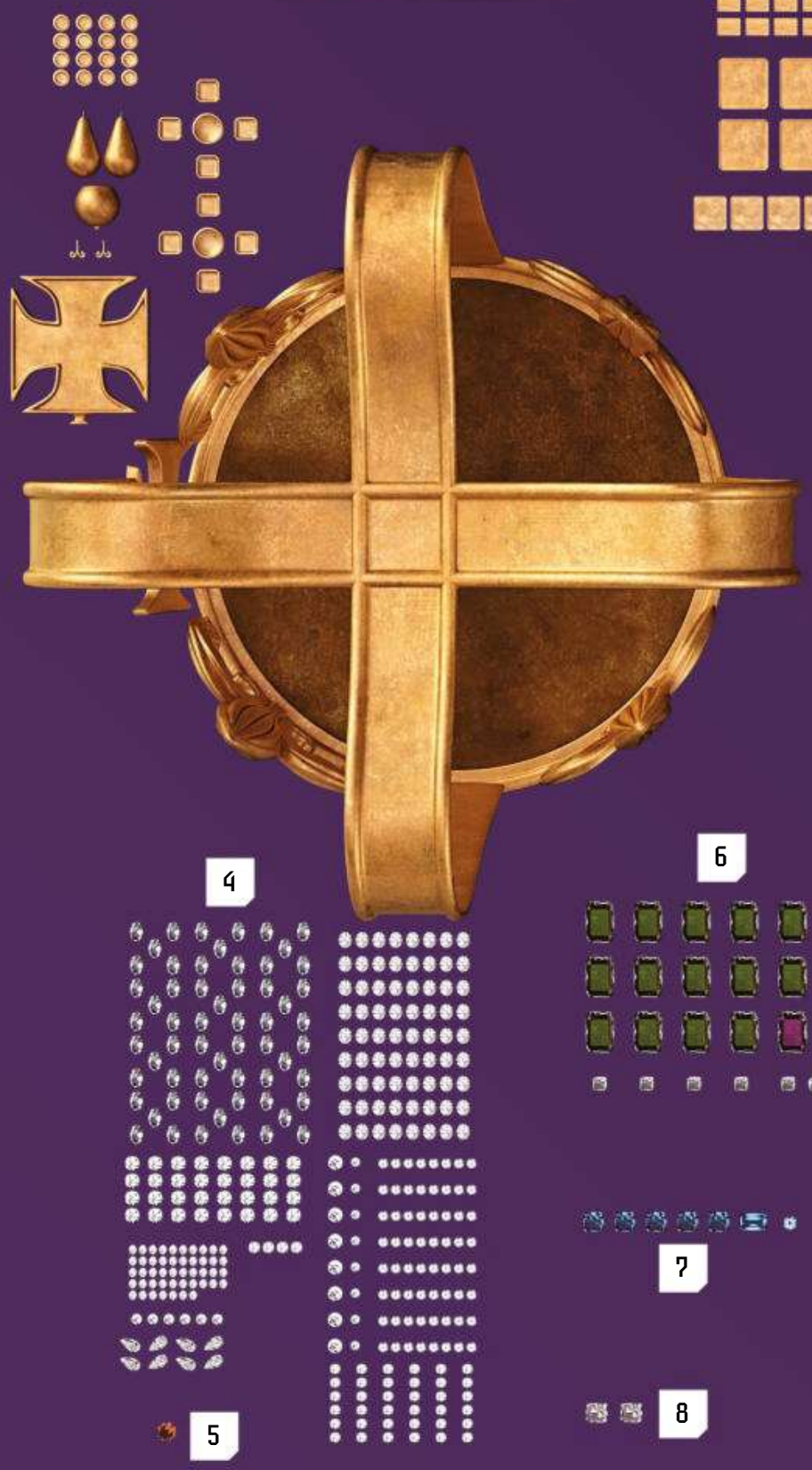
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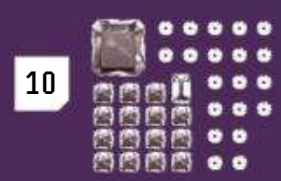
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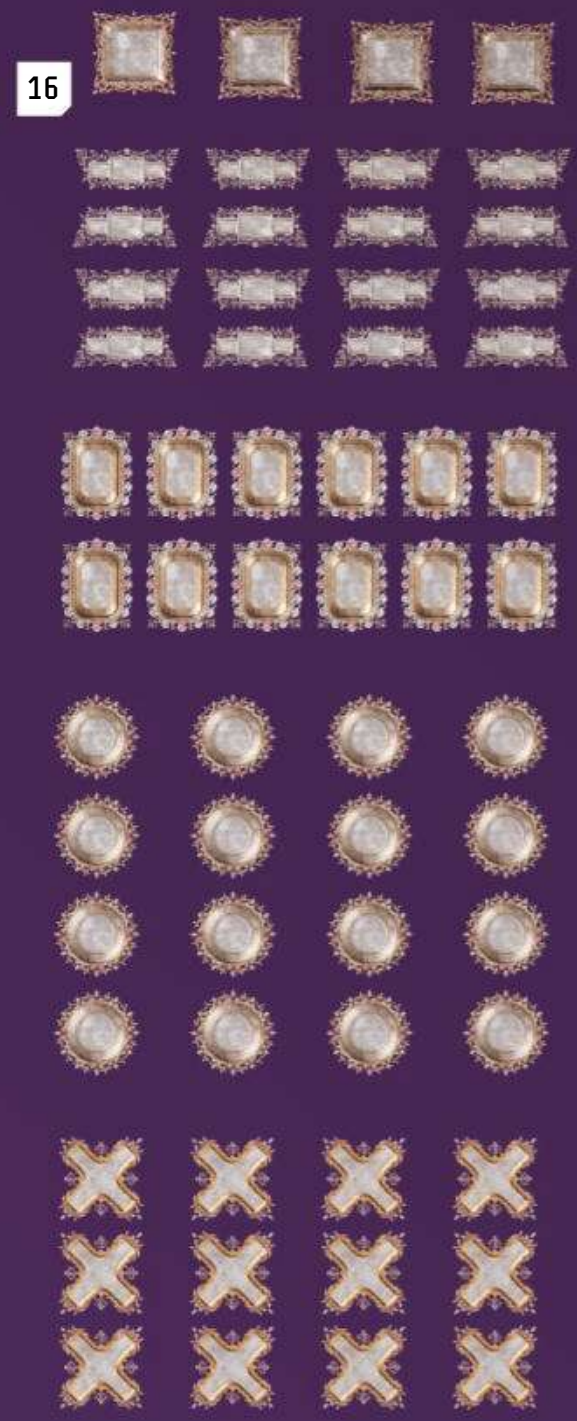

16

DID YOU KNOW? The anointing oil contains oils of orange, rose, cinnamon, musk and ambergris

St Edward's Crown

444 stones make up the coronation crown

1 ERMINE
£30
The crown has an ermine fur band. These weasel-like animals symbolise moral purity. A traditional view of ermine is that they would do anything to prevent tainting their bright-white coats.

2 22-KARAT GOLD
£74,000
The crown's base, headband, crosses, arches and fleur-de-lis are all shaped out of gold.

3 VELVET
£3
To keep the monarch's head warm, there's a velvet cap attached underneath the golden headpiece. Purple traditionally portrays elite status because the dye needed to produce the colour was once very rare.

4 ROSE-CUT AQUAMARINE
£145,800
345 pieces of aquamarine embellish the royal crown. The gemstones are mined mainly from Brazil, Nigeria, Madagascar, Zambia, Pakistan and Mozambique.

5 CARBUNCLE
£2,100
One piece of deep-red almandine gemstone, called a carbuncle, sits centrally beneath the crown's main cross.

6 TOURMALINE
£291,600
These stones, found largely in Africa, contain boron-silicate minerals and vary in their elemental makeup. Differing concentrations of magnesium, sodium, aluminium, iron, potassium and lithium give the crown's 26 stones a range of colouring.

7 SAPPHIRES
£1,810,500
These blue stones originated from Asia and traditionally signify nobility, truth, sincerity, faithfulness and protection from harm.

8 ZIRCONS
£2,600
These stones come in different colours. When yellow, like on St Edward's crown, they're called jargons.

9 GARNET
£2,100
This stone has the biggest range of colours of them all. In the crown the garnet is red and has a similar appearance to a ruby.

10 TOPAZ
£31,200
37 white topaz pieces adorn the crown.

11 AMETHYSTS
£4,200
During the Middle Ages, these purple quartz crystals became a symbol of royalty.

12 PERIDOT
£470
This green rock is composed of the mineral olivine. However, it's thought that this one peridot piece was mistaken for an emerald when the crown was commissioned.

13 CITRINE
£3,790
These four yellow quartz stones were very rare in their natural form. Now citrine can also be made by heat-treating amethysts.

14 ALMANDINE
£3,000
15 pieces of almandine add colour to the crown. This garnet was originally sourced from the town of Almandine in the Anatolian peninsula.

15 SPINEL
£38,000
Spinel is chemically different to a ruby because it has magnesium in it as well as rubies' aluminium, oxygen, and chromium. When this crown was made, the spinel would have been classed as a ruby.

16 OTHER MATERIALS
£79,730
All other non-gem materials, including precious metal settings that aren't part of the crown's gold framework.

Total value
£2,489,123

The Koh-i-Noor diamond was previously positioned at the top of Queen Mary's crown, as seen above

THE QUEEN CONSORT

The queen consort, who is currently Camilla, the wife of King Charles III, is presented with Queen Mary's Crown at the king's coronation. Usually, a new crown is made for the queen consort, but Camilla opted to reuse an existing crown. This is the first time this has been the case in almost 300 years. The reason behind this choice was to support sustainability. However, the crown is surrounded by some controversy. Queen Mary's crown has undergone modifications before the coronation to remove the Koh-i-Noor diamond. The Koh-i-Noor diamond was once the world's largest diamond, and belonged to India before the British Empire took it. The 106-carat diamond is being removed so that Camilla isn't flaunting a colonial past. Instead the diamond will be replaced by the Cullinan III, IV and V diamonds, which were worn as brooches by the late Queen Elizabeth II.

© Alamy / Getty / Illustration by Nicholas Forder

The sceptre and the orb

When a British monarch changes, two of the most symbolic artefacts to be presented are the sceptre and the orb. The sceptre is a large, staff-like rod which symbolises power, while the orb is a golden sphere with a cross protruding from the top. The two together are meant to represent two forms of power: their own physical power over the people and the power from a spiritual being. The sceptre is mostly symbolic of authority, derived from a shepherd's crook. Just as a shepherd guides its flock, the new monarch must guide the country. The Sovereign's Orb was traditionally incorporated to remind the monarch that their power was given to them by god. The orb is made of gold and is separated into three sections by bands of jewels to represent the three continents, which were the only continents known when the orb was first designed.

As part of the coronation ceremony, the Archbishop of Canterbury hands the sceptre to the king or queen and says: "Receive the Rod of Equity and Mercy. Be so merciful that you be not too remiss; so execute justice that you forget not mercy. Punish the wicked, protect and cherish the just and lead your people in the way wherein they should go."

Did you know?

The orb has a large amethyst at its top

The sceptre and orb both feature jewelled crosses

THE STONE OF SCONE

This large sandstone block originally belonged to Scotland, with members of the Scottish monarchy being crowned on top of it for many centuries. When England invaded Scotland in 1296, King Edward I claimed the stone and built it into his throne. Since then, the stone has featured in the ceremonies of British monarchs. The stone was incorporated as a reminder that any monarch that's crowned the king or queen of England will become the ruler of Scotland as well. In 1996, some 700 years after it was stolen, the stone was returned to Scotland, and is kept in Edinburgh Castle.

The Stone of Scone is also known as the Stone of Destiny

The Sword of Mercy (left) is also called the Curtana

CEREMONIAL SWORDS

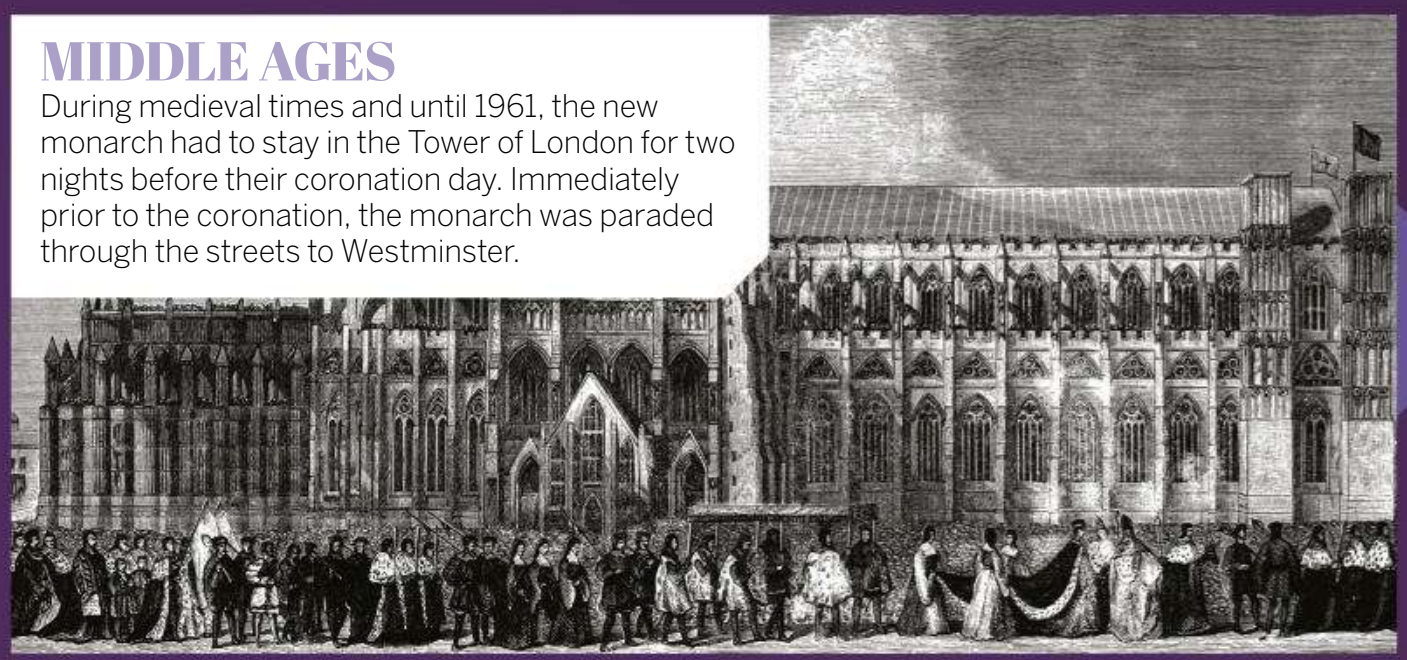
There are three swords used in a coronation procession, and each has a different meaning to serve as a reminder to the new monarch. These are the Sword of Spiritual Justice, the Sword of Temporal Justice and the Sword of Mercy, all of which have been a coronation tradition since the ceremony of King Charles I. The first two swords remind the king or queen that they need to monitor both spiritual and non-spiritual relationships. The Sword of Mercy, also known as Edward the Confessor's Sword, stands out from the others with a broken tip. The blunt end is to represent mercy and compassion. According to legend, this sword was broken by an angel as a way to prevent an unjust murder.

DID YOU KNOW? 27 million people watched Queen Elizabeth II's coronation in the UK alone

Changing traditions

MIDDLE AGES

During medieval times and until 1961, the new monarch had to stay in the Tower of London for two nights before their coronation day. Immediately prior to the coronation, the monarch was paraded through the streets to Westminster.



1300

Following England's conquest of Scotland, the coronation chair was created. This throne was first used by King Edward I, fitting the Stone of Scone underneath.

1727

The traditional coronation anthem, *Zadok the Priest*, was composed by musician George Frideric Handel. This song has been sung since George II's coronation.

1661

When the original coronation crown was destroyed during the English Civil War, a new crown was commissioned. The new St Edward's crown was made.

1382

The Royal Book, or *Liber Regalis*, was made as a rule book to guide coronations. This was a way to ensure traditions were kept.

Did you know?

Coronation chicken was invented for Queen Elizabeth II's coronation

1821

The Westminster Great Hall originally held great celebrations following a coronation. The last coronation banquet was held in 1821 for King George IV.

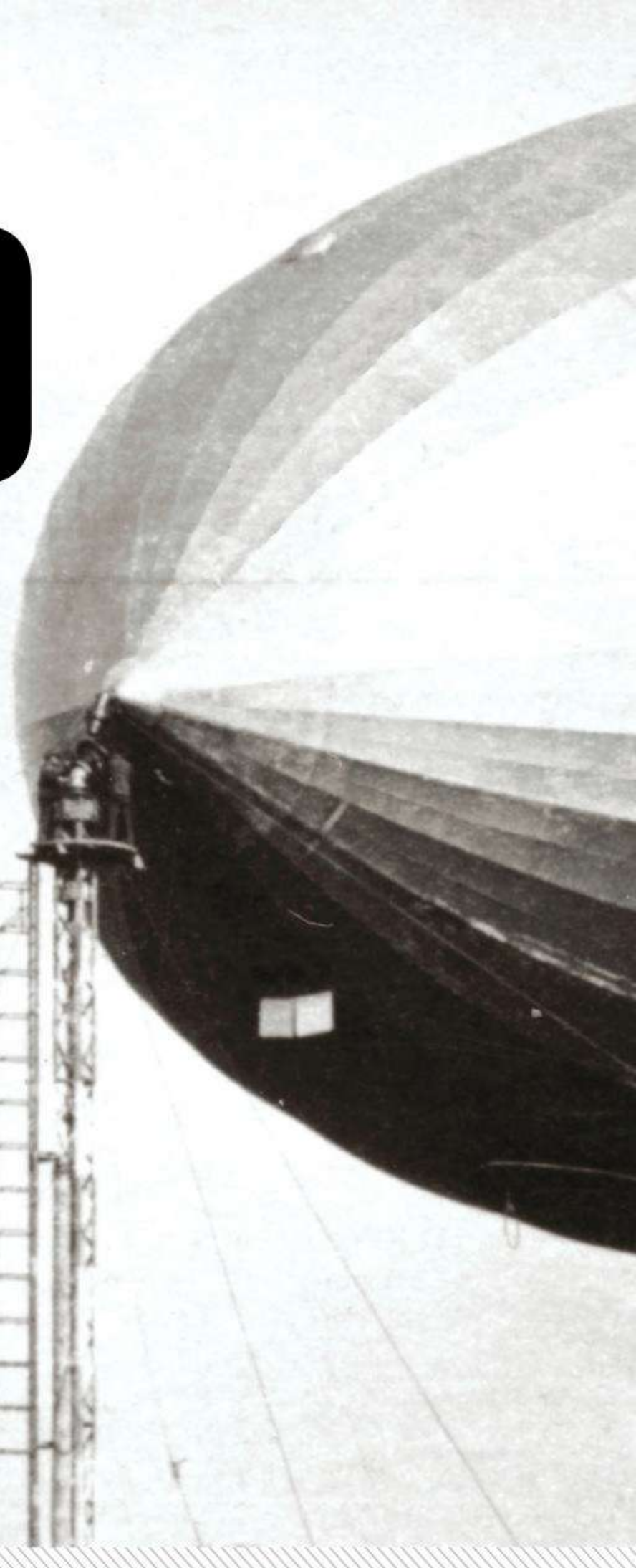
1953

Queen Elizabeth II's coronation was the first to be fully televised.

King Charles III is the first UK monarch to take the regnal name Charles for over 300 years

© Alamy / Getty

THE WEIRD WORLD OF AIRSHIPS



Pioneering aircraft that captured the imagination of a generation, airships have a brief but action-packed history

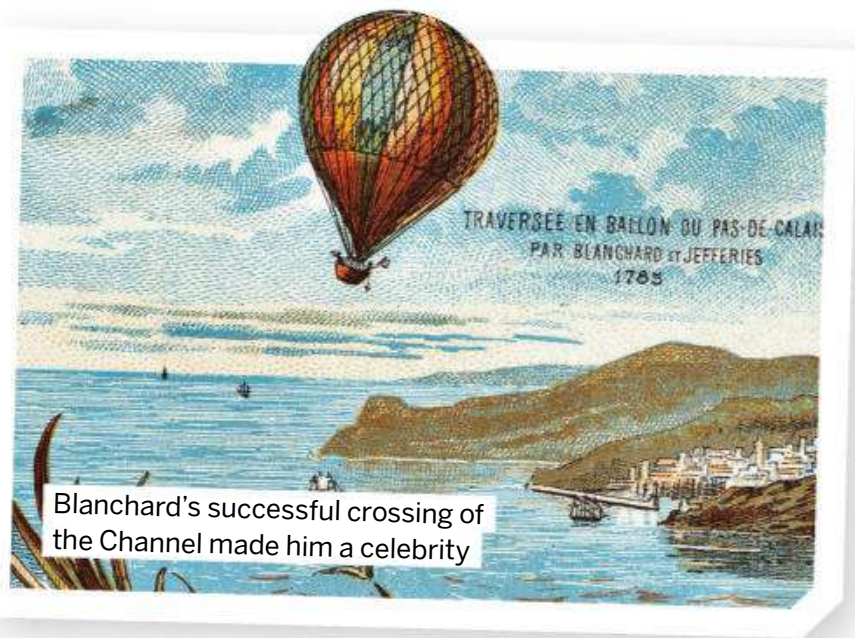
WORDS **PETER WOLFGANG PRICE**

The accepted future of air travel today is firmly in the hands of planes, but at the end of the 19th century it was airships that held the keys to the sky. Floating leisurely above the clouds, the story of these craft has often been forgotten and sidelined in favour of fixed-wing aviation achievements, but remains a key part of humanity's history of flight.

BALLOONMANIA STRIKES EUROPE

1784

Jean Pierre Blanchard was a Frenchman who dreamed of flight. The owner of an inquisitive mind, he unsuccessfully attempted to develop manual-powered aeroplanes and helicopters before finding fame with another aviation idea: hot-air balloons. In March 1784, Blanchard first took to the skies in a homemade balloon, a year after the first successful balloon flight by the Montgolfier brothers. In 1785 he teamed up with an American physician, Dr John Jeffries, and lifting off from Dover Castle flew over the English Channel to France. The journey took a leisurely two-and-a-half hours and was a world first. Blanchard's flights triggered 'balloonmania' among the public, with all manner of balloon memorabilia being produced. However, Blanchard would suffer an unfortunate end when he had a heart attack mid-air in 1808. Plummeting 15 metres to the ground caused massive injury that he would never recover from, and he died the next year.



Blanchard's successful crossing of the Channel made him a celebrity

DID YOU KNOW? Future airship spacecraft might be used to explore the clouds above Venus and Jupiter

Andrews offered his invention to the Union Army during the American Civil War, but it showed little interest

A CHANGE IN DIRECTION

1852

Just 51 years before the Wright brothers conquered the skies, the first powered flight in history was taking place. French engineer Henri Giffard had solved a major problem with balloon travel: controlled and steerable propulsion. Without this, a balloon ride was essentially a one-way trip. Creating the world's first powered and steerable airship, called a 'dirigible' from the French word for steerable, Giffard had opened the world up to the concept of lighter-than-air travel. The gas used in balloons at this time was hydrogen, which was highly flammable and dangerous, but was otherwise lighter than air, allowing for balloons filled with it to float. To power his dirigible, Giffard used a steam engine specially designed with a downwards-facing funnel and mixed exhaust fumes so as to reduce the chance of sparking – just one of which could vaporise the volatile hydrogen. Producing three horsepower and able to reach a top speed of more than nine kilometres per hour, the engine was about as powerful as a modern iron.

LOSING POWER

1863

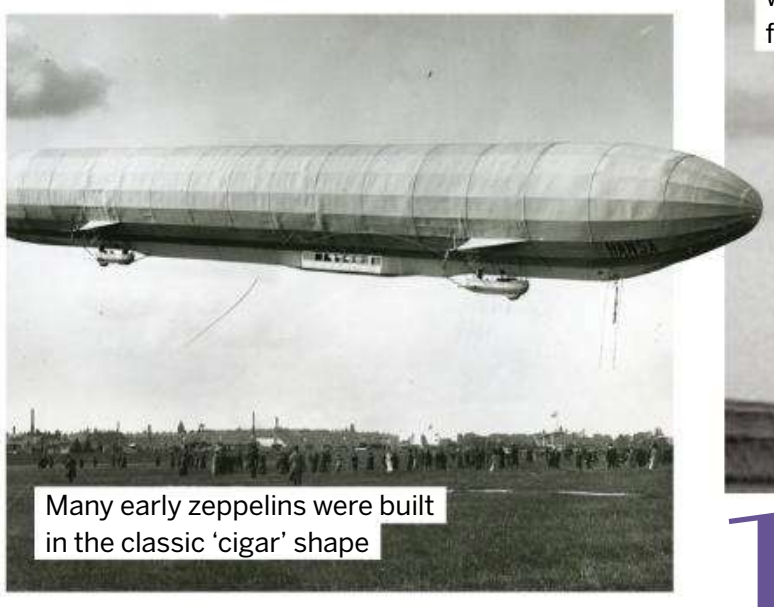
An aviator and airship inventor, Solomon Andrews had an unconventional approach to airship construction. His craft, called the Aereon, would use air currents as propulsion rather than an engine to glide through the air. This novel idea was never fully realised, as the company went bankrupt after the American Civil War. An attempt to reinvent the concept in the 1960s also failed.

© Alamy

BIRTH OF THE ZEPPELIN

1909

Count Ferdinand von Zeppelin was an aircraft manufacturer who pioneered rigid airship design at the turn of the 20th century. His passion for lighter-than-air travel was kindled in the crucible of the American Civil War when, while serving as an observational officer, he saw his first hot-air balloon. His fervour would reignite years later in 1891 when, aged 52, he resigned from the military and devoted all his attention to airships. His background as a soldier would see him push for his zeppelins to have a military application, and he is reported to have been dismayed when in 1909 the world's first passenger airline, Deutsche Luftschiffahrts-Aktiengesellschaft (DELAG), or the German Airship Transportation Corporation, was launched. While still in its infancy, the company focused more on sightseeing, taking passengers on pleasure tours around the German countryside. As interest in zeppelins grew, DELAG would carry more than 34,000 passengers on over 1,500 flights between 1910 and 1914. Despite having landing fields and hangars located all across Germany, DELAG was prevented from implementing a regularly scheduled intercity service by the outbreak of World War I. Even with this setback, thousands of people had been exposed to airship travel.



Many early zeppelins were built in the classic 'cigar' shape

"Despite having landing fields and hangars across Germany, DELAG was prevented from implementing a regularly scheduled intercity service by the outbreak of World War I"

A DARK SHADOW IS CAST

1914 to 1918

At the start of the 20th century, the major world powers had high hopes for dirigible technology and what it could bring to the war effort. Airships gave the world's air forces a viable long-range strategic bomber that could stay airborne for hours at a time. It was the Germans who seized upon the idea, and from 1915 zeppelins had robbed Britain of the protection that the English Channel offered and were terrorising its citizens in a strategic aerial bombing campaign. The deliberate bombing of civilians was unheard of before this, and public outcry was fierce. A floating bag of extremely flammable gas may not seem like the best asset to use as a bomber, but during the early missions they were actually quite difficult to destroy. Until a special type of ammunition was created that combined explosive and incendiary rounds, bullets were just as likely to pass straight through a zeppelin's gasbag than ignite it. This heyday would be short lived, however, as aircraft technology was improving at astonishing speed. By the end of the war, airships became obsolete in an offensive capacity but were maintained in reconnaissance roles. They'd heralded the way for a new type of warfare: mass civilian bombing.

Germany transformed the zeppelin into a weapon

After completing 590 flights, the Graf Zeppelin was scrapped for fighter plane parts

1919 GERMAN AIRSHIP PRODUCTION RESUMES

Germany's surrender in World War I was finalised by the signing of the Treaty of Versailles. This forbade Germany from maintaining any airships that could be used for military purposes and stipulated that any airship still in service be handed over to the Allied Powers. This presented a problem for the zeppelin business, and their innovative new craft, the LZ 120 Bodensee, was repossessed and given to Italy to pay war reparations. The company even had to resort to manufacturing aluminium cutlery to stay afloat. The light at the end of the tunnel came when the company managed to secure a manufacturing contract with the US and built the LZ 126, which was flown over to be delivered in August 1924. Ecstatic crowds awaited its arrival, and President Calvin Coolidge called it an 'angel of peace'. This success breathed new life into Luftschiffbau Zeppelin, with the Locarno Treaties easing the restrictions of airship construction in Germany.

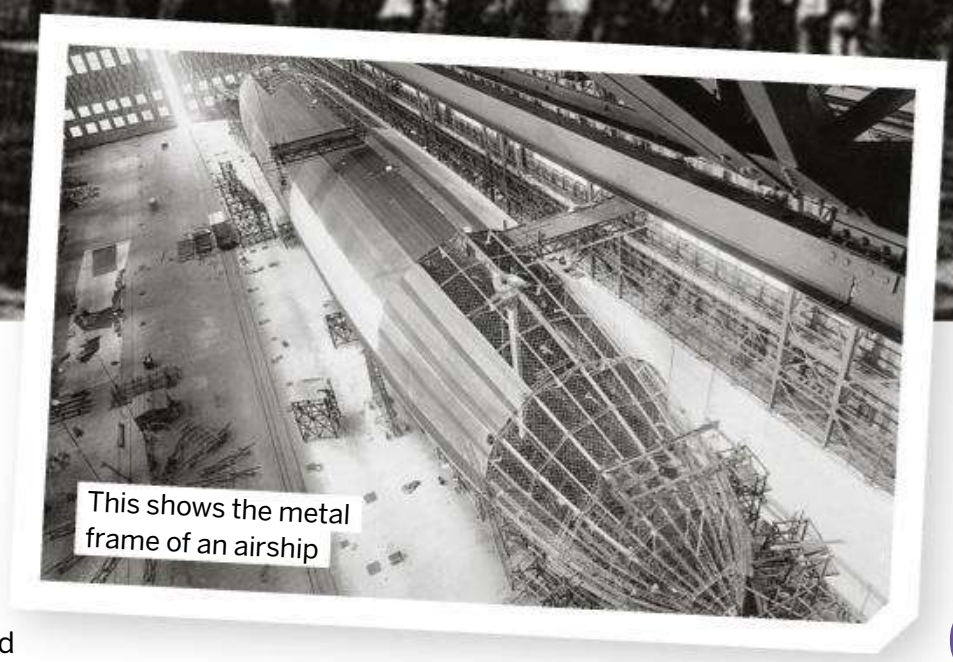
Luftschiffbau Zeppelin went on to build one of its most famous ships in 1928: the Graf Zeppelin. This huge vessel was more than three times the length of a Boeing 747 and the largest airship ever built at the time. The Graf Zeppelin became the flagship for Luftschiffbau Zeppelin, making trips to Jerusalem, Britain, Egypt and the Arctic, and made DELAG the first airline company to offer transatlantic trips from Europe to South America. Even though fixed-wing aircraft technology was fast improving, the popularity of the Graf Zeppelin kept airships firmly fixed in the public's mind.

DID YOU KNOW? Today blimps are used to advertise products and film sporting events from the sky

Despite helium being the safer gas, its higher cost meant that hydrogen was still used until the late 1930s

FIRST HELIUM AIRSHIP
1921

On 1 December 1921, the US Navy blimp C-7 sailed into the sky. It was the first airship to be filled with helium, not hydrogen. Helium, being an inert gas, was far safer to use in these temperamental machines, but did not generate as much lift.



This shows the metal frame of an airship

ADVERTISING ADVANCES
1925

With the airship market booming, the Goodyear Tire and Rubber Company saw an excellent marketing opportunity. Christened Pilgrim, its first advertising blimp was launched in July 1925 with resounding success. The company's president had them named after competitors in the America's Cup yacht race, as he saw that airships could "serve a similar purpose for persons living inland as do yachts for those living along the seacoast". The burgeoning airship industry had created a romantic image around itself, and Goodyear's blimps were seen as embodying the spirit of the Roaring Twenties. Publicity stunts and feats of daring were carried out with acrobats and wing walkers, exciting and wowing crowds across the US. Today, Goodyear still maintains its airship fleet and is in the process of replacing all its blimps with semirigid designs. Although these are not technically blimps, the aircraft have become such a well-known sight that the name has stuck.

TRAGEDY AT SEA
1925 ONWARDS

After World War I, the US became interested in airship technology for the military. Commissioning a number of ships from both German and British manufacturers, the US Navy began to build its airship fleet. Danger was never far behind, and the first in a series of tragedies struck in 1925 when the USS Shenandoah ran into a storm and was torn apart, killing 14 crew. Although improvements to airship designs were made, one of the deadliest accidents would occur just eight years later. Caught in a lightning storm off the coast of New Jersey, the USS Akron was lost, leaving only three survivors. Akron's sister ship, the USS Macon, would suffer a similar fate, but mercifully almost all of the 81 crew survived thanks to their life rafts.

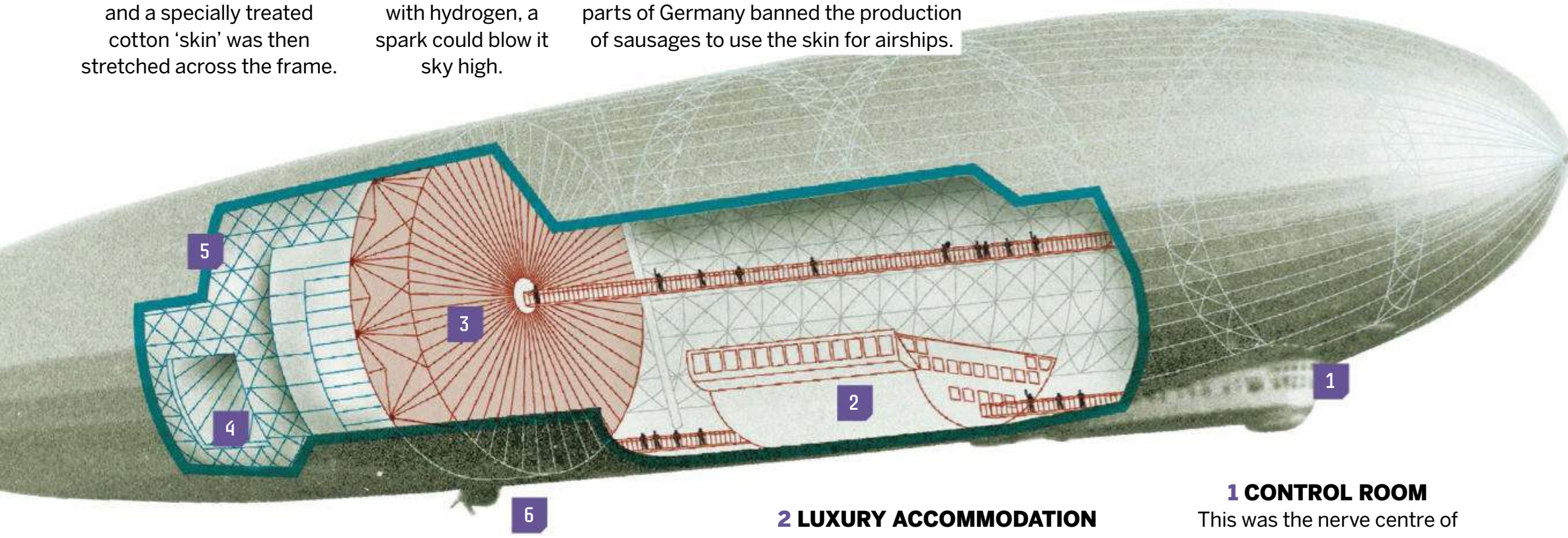
© Alamy

INSIDE THE LZ 129 HINDENBURG

5 FRAMEWORK
The Hindenburg's structure was composed of girders made from an aluminium alloy know as duralumin. These were fused together and a specially treated cotton 'skin' was then stretched across the frame.

4 FINDING LEAKS
A leak in a gas bag could spell disaster for an airship. Either the ship could lose altitude or, if filled with hydrogen, a spark could blow it sky high.

3 GAS BAGS
These bags were used to store the hydrogen gas that gave the airship its lift. Early bags were made from cow intestines in a similar way to sausage skin. Demand was so great in World War I that parts of Germany banned the production of sausages to use the skin for airships.



6 ENGINE ROOM
Maintenance of the ship's engine would mean not minding the deafening noise or cramped conditions. At high altitude, the air would become extremely cold, but this wasn't a problem for engineers in one of the only warm spots on the airship.

2 LUXURY ACCOMMODATION
Travelling on the Hindenburg meant travelling in style. The passenger cabin was the equivalent of a five-star hotel equipped with a dining room serving three-course meals and an observation lounge.

1 CONTROL ROOM
This was the nerve centre of the ship, where the captain, navigator and wireless operator were all positioned. The steering and course plotting all occurred here, with engineers being located nearer the engine room.

THE SOVIET AIRSHIP PROGRAM CRASHES
1930s

Beginning as far back as the Napoleonic Wars, Russia's airship program was quite successful, if not a little mysterious, with few official records surviving. Soviet engineering would produce some amazing results with the SSSR-V6 OSOAVIAKhIM, beating the German record for endurance flying by staying airborne for a staggering 130 hours. After World War II, Russian airships fell into decline, and by the 1950s they were grounded.

IMPERIAL AIRSHIP SCHEME NOSEDIVES
1930

At the height of its power, the British Empire spanned a quarter of the globe. Travel between its borders could take months. The solution was the Imperial Airship Scheme. Two ships were initially commissioned: the R100 and R101. The committee that was assigned to aid construction would cripple it, however, imposing implausible restrictions and ignoring safety warnings. As previous airship disasters were fresh in the public's mind, the R101's metal frame was made far stronger than required, leading to the airship having unnecessary weight. It would also become woefully underpowered, as the craft was forbidden from having petrol engines for fear they would explode in India's heat. The diesel engines it was fitted with were originally designed for railways and came in much heavier than planned. In the haste to launch, the concerns voiced by engineering personnel were silenced, and on 4 October 1930 the R101 left Cardington heading towards Karachi, Pakistan. Hampered by stormy conditions and faulty engines, the R101 dived nose first into French soil, ending the Imperial Airship Program and grounding the rest of the fleet.

THE WORLD'S HIGHEST AIRSHIP DOCK
1931

Being one of the tallest buildings in New York, it was inevitable that the Empire State Building would be used to tether airships. A seemingly inspired idea turned out to be a bust as a combination of powerful updrafts and a lack of ground mooring lines made the building a death trap for the craft.

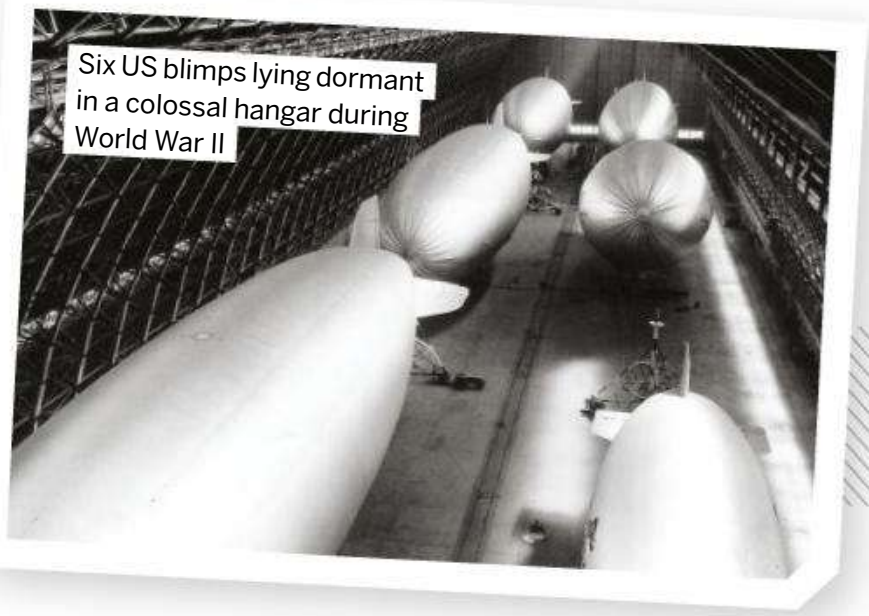
DID YOU KNOW? 19 September 1783 marked the first hot-air balloon flight

THE HINDENBURG DISASTER

1937

On 3 May 1937, the Hindenburg left Frankfurt on what would become its final flight. Coasting leisurely across Europe and the Atlantic, it arrived over the glittering skyscrapers of New York on 6 May. The landing had been delayed due to poor conditions, and it was attempted again in a small window of calm at Lakehurst, New Jersey. The ship caught fire and was ripped apart in an explosion that lasted just 30 seconds. Of the 97 people on board, 35 lives, both civilian and crew, were lost, as well as the life of one ground worker. The cause of the disaster stumped experts. The captain maintained that it must have been sabotage, while other theories included lightning or the natural phenomenon of St Elmo's fire. Now scientists believe that it was a single spark that caused the catastrophe.

In an ominous twist of fate, the Hindenburg was constructed out of the wreck of the R101



Six US blimps lying dormant in a colossal hangar during World War II

WORLD WAR II

1939 to 1945

The demand for the use of airships in World War II was still high. It would be the Americans, however, not the Germans, that would fully utilise them. Hermann Göring, the head of Germany's air force, was famously distrustful of airships, and owing to aluminium shortages had the majority of Germany's fleet melted down in 1940. The US Navy, after the attack on Pearl Harbor, realised that it simply did not have the ships or aircraft to defend more than 11,800 miles of US coastline, and so turned to airships for help. The US would utilise airships fully in the conflict and tasked them with small but important roles such as minesweeping, photo reconnaissance, search and rescue and anti-submarine patrols. Their top-down view enabled them to spot telltale signs of enemy submarines better than a ship on the surface and could radio coordinates for battleships to intercept. Over four years of war, only one ship was lost to enemy fire when a K-74 was brought down by a German U-boat. The ship gave as good as it got, damaging the U-boat so much that it could no longer submerge, and it was soon sunk by bombers.

END OF AN ERA

The destruction of the Hindenburg was the death knell for commercial airship production, both in Germany and internationally. With plane technology allowing for much faster travel times and cargo capacity, the demand for airships both before and after World War II plummeted. While still used in a very limited capacity in advertising and military applications, these craft have all but flown from the public mind. However, renewed interest could see an airship renaissance. In 1997, Luftschiffbau Zeppelin re-emerged, producing its first new model in 50 years, with the Zeppelin NT 07 making its maiden flight. Another company, Aeroscraft, was recently given a large grant by the US government to produce the next generation of airships. Apart from tourism and advertising applications, airships are ideal for research and environmental missions due to their low vibrations and ability to haul cargo to inaccessible locations that might not be served by a road, port or runway.

Aeroscraft's prototype was destroyed when the roof of its hanger collapsed

© Alamy

5 FACTS BLIMPS AND ZEPPELINS

1 AIRSHIP
An airship is a steerable, powered aircraft inflated by lighter-than-air gases.

2 DIRIGIBLE
A synonym of airship, the name comes not from its rigid frame, but rather the French word diriger, meaning 'to steer'.

3 BLIMP
A blimp is an airship that has no rigid structure and maintains its shape from the pressure of the inflating gas.

4 RIGID AIRSHIP
These craft maintain their shape not through the pressure of the lifting gas but by a rigid framework that surrounds the gas cells or bags.

5 ZEPPELINS
A rigid airship built by the Zeppelin Company Luftschiffbau Zeppelin founded by Count von Zeppelin.

How we taste food

WORDS AILSA HARVEY

Discover the chemicals that combine to create an extensive assortment of flavours

DID YOU KNOW? Vanilla was first used as a flavour in the 1500s

Food is essential to life, and all animals eat to gain the necessary energy for survival. Since the dawn of agriculture, people have experimented with different foods' potential and learned how to turn cooking into an art. The art of flavouring requires not just taste intuition, but an understanding of the chemistry of different foods and their complementary pairings.

Today, chemists and chefs experiment with flavour combinations to create unique taste profiles for your tongue. The human body experiences flavours by combining the senses of smell, taste and touch. Your tongue is covered in sensory cells, which are packed into groups called taste buds. These protrusions on the surface of the tongue are stimulated by five main types of food flavour: sweet, salty, sour, bitter and umami. For a flavour to be processed, the food must be dissolved in water and come into contact with the taste buds. Food that has little or no water content relies on saliva that's released into the mouth to instigate the taste sensation.

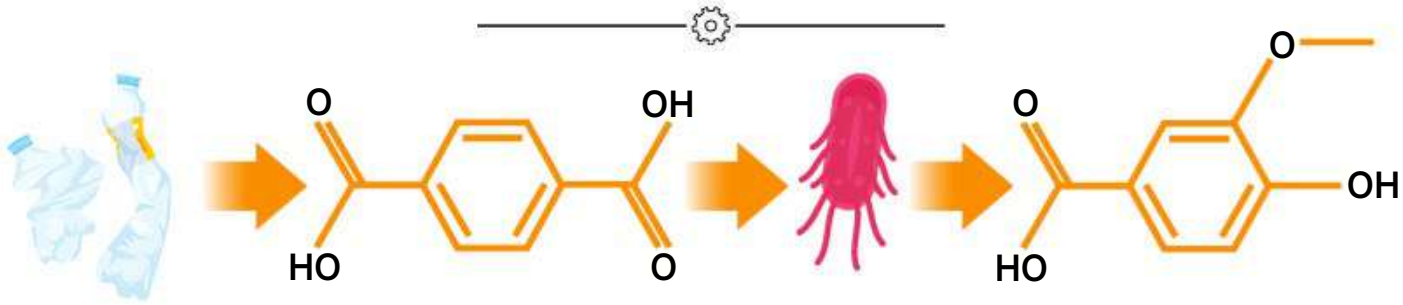
Between individuals, flavour preferences can vary. Your favourite food is likely to be different to your friends', and a food that you can't stand might be a staple in someone else's diet. Our flavour preferences depend on our genes, experience and age. How your taste buds interpret flavour sensations can change as you get older, making some bitter foods more tolerable for adults than you remember them being when first exposed to them as a child. Meanwhile, the foods that a pregnant person includes in their diet influence a child's flavour preferences when they're born. Despite our interpretations of flavour being personal, to some extent humans share the same core attraction to sweet flavours.

Did you know?

Oily secretions from near beavers' anal glands can make vanilla flavouring

STEP BY STEP

How vanilla is made from plastic waste



1 PLASTIC WASTE
A lot of plastic waste contains a strong, clear plastic called polyethylene terephthalate (PET).

2 TEREPHTHALIC ACID
This acid is found in PET plastic and has a similar chemical structure to vanillin.

3 E. COLI
Bacteria such as *E. coli* can be genetically engineered to reorder the hydrogen and oxygen atoms of terephthalic acid.

4 VANILLIN
After placing the *E. coli* and terephthalic acid in contact at 37 degrees Celsius for a day, the majority of molecules convert into vanillin.

WORLD'S FAVOURITE

Some people might think of vanilla as a bland flavour, but the subtle sweetness extracted from the pods of vanilla orchids contain the world's most popular compound. This compound is called vanillin ($C_8H_8O_3$), providing the distinctive vanilla flavouring often incorporated into sweet treats. Annually, over 18,000 tonnes of vanillin is used to make flavours and fragrances. However, only one per cent of vanilla flavouring is sourced from vanilla pods. Vanillin is often synthetically produced by breaking up similar compounds in various oils like clove oil, and even in materials such as wood and plastic. This is a cheaper and less labour-intensive method of creating enough vanillin to match global demand. Volumes to match the current consumption of vanillin couldn't be reached if manufacturers relied on the natural source alone.

Vanilla pods need to be soaked to extract their natural flavouring

The beans of a castor plant are poisonous. Their potent toxin ricin has a highly bitter flavour

THE EVOLUTIONARY PURPOSES OF FLAVOUR

The human body needs a diverse range of foods in order to stay strong, active and healthy. Today it's well documented which foods have beneficial nutrients, as well as those that should be avoided. But during earlier stages of human evolution – when people had to forage and hunt for food in the wilderness – the flavour of different plants could help guide people's diets and increase their chances of survival. Generally speaking, sweeter-tasting foods have more energy-dense nutrients, while bitter flavours are detected in toxic foods. Before the science behind micronutrients was known, these flavours attracted humans to the right foods and deterred them from eating something harmful. Taste buds adapted to suit this pattern increased the person's chances of survival and was passed down across generations, shaping how flavour is interpreted today.

Another way in which flavour has benefited our survival abilities is by allowing the body to store energy better. For example, how many times have you felt the sensation of being full to the brim after your main course, only to find yourself eating a sweet dessert just minutes later? The body is programmed to stock up on foods of different flavours and nutrients. This helps humans take advantage of times when there's lots of food available and keep them going through periods when food is scarce or depleted.

© Getty

NATURAL VERSUS ARTIFICIAL

Can nature's tastes be recreated, and how do they compare?

The simplest way to add flavour to a product is to use natural ingredients. Natural flavourings are chemical compounds that are taken directly from nature, such as from herbs, spices, fruit, vegetables, animals or yeast. When you see the term 'natural flavours' on food packaging, the connotations may be of pure, unprocessed ingredients. However, in many products the flavour compounds still undergo processing. These compounds may be tweaked slightly to keep a consistent product taste, but because it was originally sourced from natural produce it still counts as a natural flavour. Some of the most common natural flavour sources are strawberries, oranges, lemons, anise and ginger. The flavour of a natural strawberry is one that's difficult to replicate without using a strawberry itself. This is why artificial strawberry flavours can differ by product and rarely taste the same as the true fruit. A strawberry's flavour is a combination of sweetness and bitterness. As the fruit ripens it becomes sweeter, but the main compounds that give it its distinctive flavour break down quickly when isolated from the fruit. Without keeping all the core flavours, the lab-created version doesn't have as close a resemblance as the artificial creations of ginger or orange.

Did you know?

It can take 70 to 80 attempts to closely match a flavour in a laboratory

BUBBLEGUM

Bubblegum has a unique flavour. It was invented in 1928, but it's also used as a flavouring for many types of sweets and drinks. Although the name and taste are now recognisable, how would you describe its flavour to someone who had never experienced it before? Bubblegum has a fruity taste that's composed of the flavour compounds from strawberries, bananas and cherries, and in some cases oranges, lemons and cinnamon. The exact original recipe remains a secret, but many other companies have their own slightly varying takes on the famous taste.

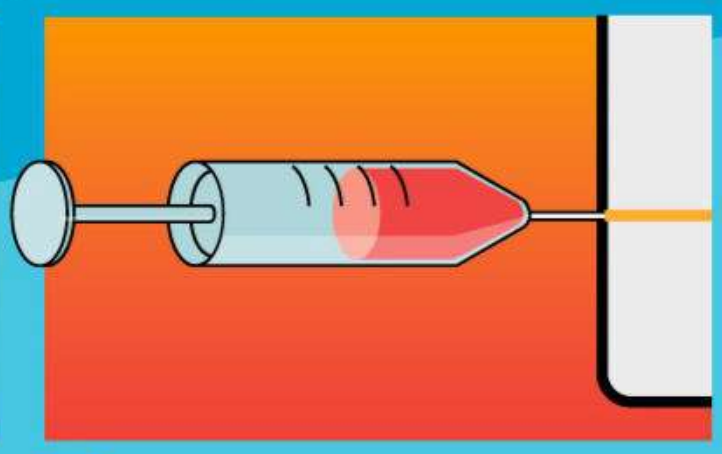
Gum was originally very grey, so pink dye was added to hide this

COMPLEMENTARY COMPOUNDS

How gas chromatography is used to find important flavour compounds

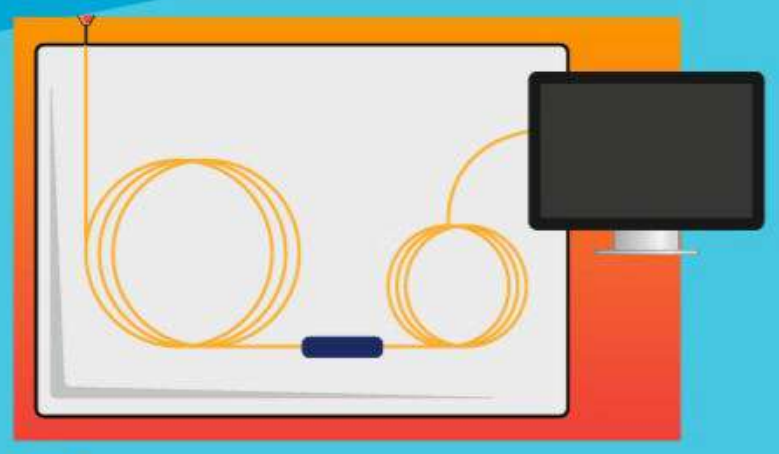
1 TARGET FLAVOUR

To analyse a flavour profile and replicate it, a natural food or a combination of foods are put into a gas chromatography machine to separate the compounds.



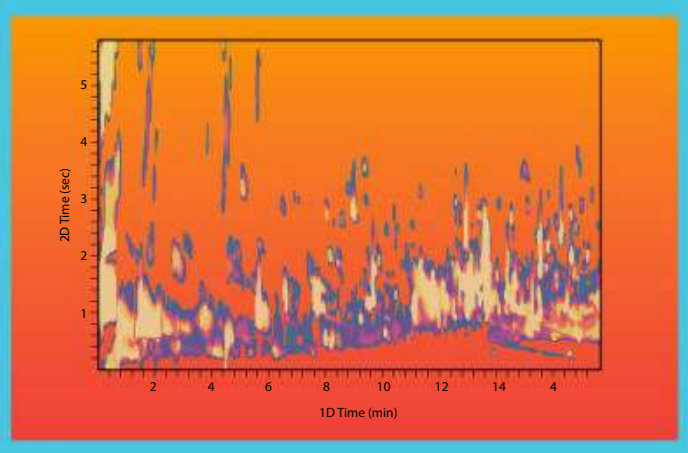
2 LIQUIFY

Only gas and liquid can enter a gas chromatography machine, so the flavour is usually created in liquid form.



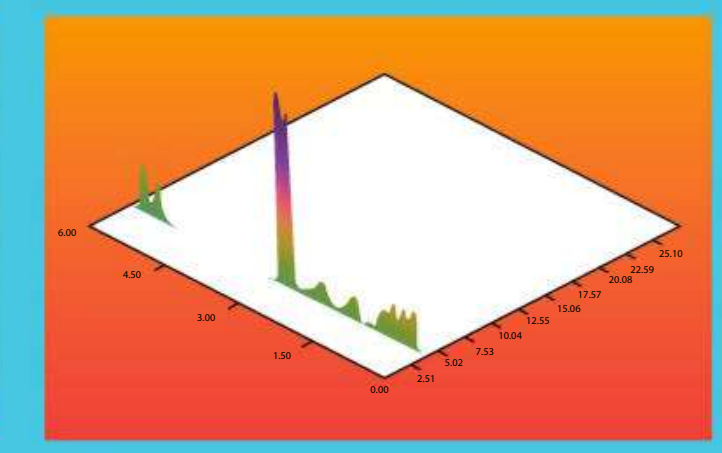
3 SEPARATE

The flavour compounds are dissolved in a solvent and then vaporised inside coiled tubes, ready to be counted and analysed.



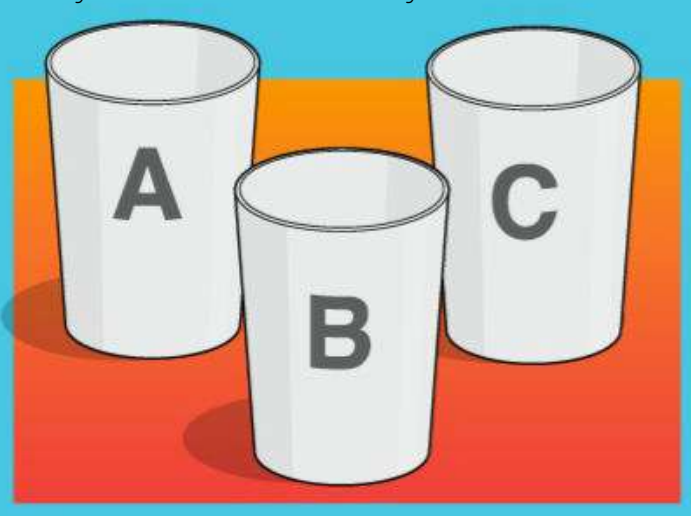
4 DIGITAL RESULTS

The types of flavour compounds are shown digitally on the device's computer. The tallest spikes show the compounds with the highest concentration. These are the most essential to produce when recreating the flavour artificially.



5 REMOVE ANOMALIES

Some of the compounds that enter the device are contaminants, or have little influence on the flavour. These are removed from the flavour components. After scientists artificially produce the flavour, it's run through the machine again to check how similar the composition is through trial and error.



6 FLAVOUR MATCH TEST

When scientists are happy with their matched flavour, a blind test is conducted. Three samples, including the new flavour and the natural flavour, are tasted without labels. If the testers all guess different cups as the suspected original flavour, the artificial one is closely matched to its target flavour.

DID YOU KNOW? Ben and Jerry's ice cream has strong flavours because co-founder Ben Cohen has no sense of smell

Different combinations of chemicals are tested in flavour laboratories

DOES ARTIFICIAL MEAN UNHEALTHY?

Artificial flavours are made of flavour molecules that have been modified from other compounds. However, when they are produced they have an identical chemical composition to the flavour chemicals taken directly from nature. Artificial compounds are often considered to be less healthy, but this is mostly due to the foods they're added to being heavily processed and unhealthy. The flavour chemicals themselves may actually be safer to consume in some instances, as they are made in laboratory conditions and require stricter quality checks.

Natural chemical compounds are organically produced, but are more likely to experience environmental damage.

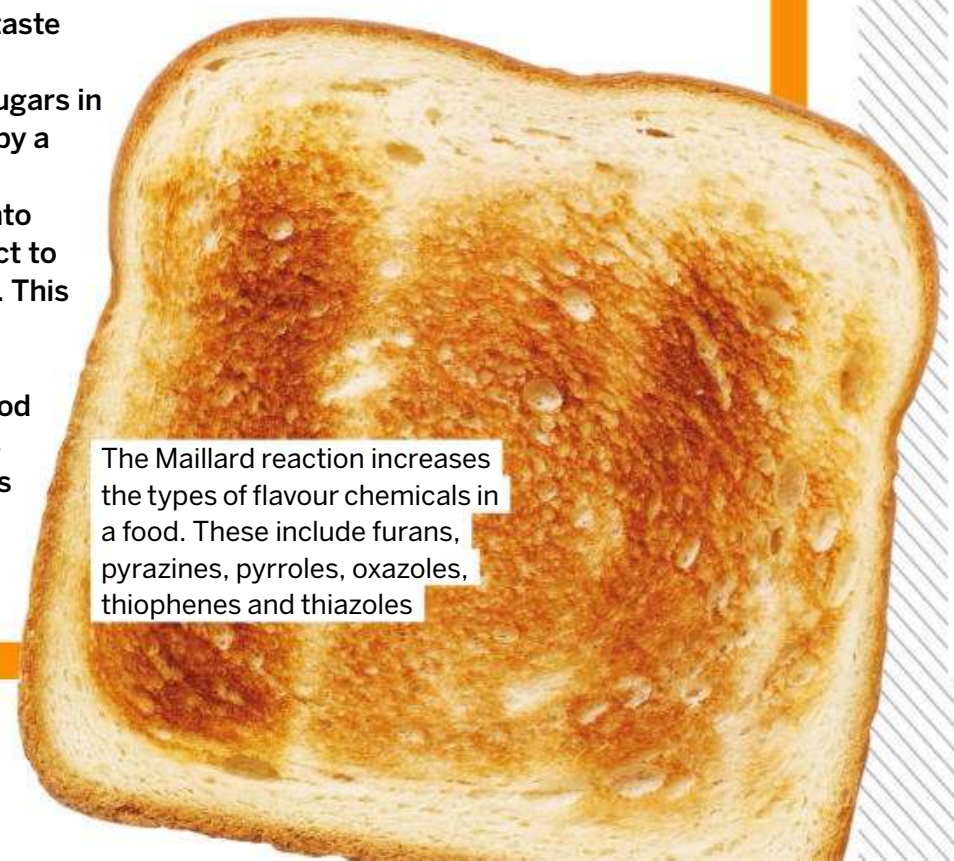
Artificial flavours are composed by flavourists or flavour chemists. These people are trained to ensure that the flavour chemicals that they mix together in food products are both complementary – matching customers' favourite flavours and flavour trends – as well as being safe for consumption. If a new flavour is invented, the compounds need to pass extensive tests before being added to any consumer products.

HOW COOKING CHANGES FLAVOUR

Do you prefer the taste of bread or toast? The taste of the two is so different that you can probably answer this question without much analysis. Not only does putting bread in the toaster give it a crunchier texture with warm surfaces, but the browning provides a caramelised flavour. How is it possible for the pop of the toaster to release such a great taste transformation?

As the proteins and sugars in some foods are heated by a fire or appliance, they rearrange themselves into ring formations and react to produce new molecules. This process is called the Maillard reaction. The temperature that the food is exposed to influences how quickly the surfaces dry out, and therefore when the Maillard reaction begins.

For this to take place, a food needs to have reducing sugars, proteins called amino acids and water. If you have ever wondered why foods such as meats turn brown quicker when you increase the heat, this is because the surface is heating and losing water at a fast enough rate for the Maillard reaction to occur.



The Maillard reaction increases the types of flavour chemicals in a food. These include furans, pyrazines, pyrroles, oxazoles, thiophenes and thiazoles

FLAVOUR EXPERT GABBY SMITH

Smith works at Ben & Jerry's Ice Cream. Her role is to develop new flavours in food laboratories, ready to be mass produced by ice cream factories

How are new flavours decided at Ben & Jerry's?
We always ask our expert consumers what they want to see from us and whether the products we are developing suit their needs. We also have a team of consumer insight experts who provide data on trends already in the market and what may be coming in the future.

What flavours are the easiest and hardest to recreate in the laboratory?
For me, the easiest flavours to recreate are chocolate flavours. Everyone loves chocolate, and you can never have too much of it. The hardest flavours to recreate for me are nostalgic flavours, as everyone has their own memories of these, so trying to meet expectations can be quite difficult.

What kinds of ingredients are added to your ice creams?
At Ben & Jerry's we use all-natural ingredients and flavours to make our ice creams. These can be fruit purees, nut pastes, flavour extracts and other natural flavourings. We have expert product developers and chefs who work together to create the best combination of ingredients.

What's required to be a flavour expert?
Taking a new flavour from concept to launch is a big task. You need to be creative with a passion and love for food and you also need good project management skills.

How difficult is it to reach the desired flavour proportions?
Depending on the flavour, it can take a long time to make sure we have the flavour balance just right. We usually have multiple tasting sessions with the whole Ben & Jerry's team for one flavour, where we taste different proportions just to make sure we pick the perfect one.

What happens after a flavour is made?
We then take our newfound flavour to our factories, where we trial the product at a much larger scale. Once this is complete, we as a team assess the new product to make sure that it's a match to what we created in our laboratory.

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Decontamination operatives handle potentially hazardous substances

HOW RADIATION SUITS WORK

These garments stop this invisible form of energy from wreaking havoc on the human body

WORDS **SCOTT DUTFIELD**

Whether it's the first responders to a radioactive detonation, radiographers conducting an X-ray examination or nuclear power plant workers, radiation-resistant garments can help prevent the harmful effects caused by radioactive substances through a process called irradiation. There are four major types of radiation: alpha, beta, neutron and electromagnetic. Each comes with its own health risks, from causing skin burns to mutating and damaging DNA, which can lead to the development of cancer.

Some radiation is easier to block than others. For example, alpha particles, such as those released from uranium, can be blocked by a piece of paper or your skin. But when those particles are inhaled through the nose, they can lead to lung cancer. Some electromagnetic waves, on the other hand, such as gamma rays, require thick layers of material such as lead to block them completely.

To prevent these types of radiation from entering and wreaking havoc on the human body, specialised hazardous materials suits are deployed. The term 'hazmat suit' is used to cover a range of protective gear. This may include suits designed to shield the wearer from biological hazards, chemical exposure and viruses, whereas others can be used to block particles of harmful radiation.

A suit to protect against radiation can do so in two ways. First to act as a physical barrier against radioactive particles, and secondly to absorb the radiation before it reaches the body. Alpha and beta radioactive particles lack the energy needed to pass through a range of materials that can be used to make a suit, such as plastics. Heavy metallic elements such as lead and boron can also be included in suit materials to absorb the energy of some types of radiation, preventing them from reaching the body. Currently, the majority of radiation suits work to block alpha and beta radiation. However, there's no full-body suit that's capable of shielding the wearer against deadly ionising radiation such as gamma rays.

Did you know?

At least 0.25 millimetres of lead shielding can block X-ray radiation

FIGHTING SPACE RADIATION

To venture beyond Earth's protective atmosphere, astronauts are equipped with suits designed to protect them from the effects of harmful radiation when outside their spacecraft. Now, as astronauts are planning to journey back to the Moon in NASA's Artemis program, anti-radiation technology is being put to the test on the latest lunar mission.

Artemis astronauts of the future might journey to the Moon wearing a new piece of anti-radiation technology being trialled called AstroRad. StemRad, a developer of anti-radiation suits, and Lockheed Martin, an aerospace company, have developed the technology to protect astronauts' vital organs from gamma radiation. AstroRad is a personal radiation shield made of polyethylene that protects specific stem cell-producing parts of the human body, such as bone marrow, which are the most susceptible to mutations caused by gamma radiation. AstroRad was strapped to the chests of mannequin astronauts aboard the first Artemis test last year. The high-tech mannequins collected vital data on how well AstroRad fared in space, which scientists can use to improve the technology for future missions.

An AstroRad vest aboard the International Space Station in 2020

DID YOU KNOW? Within Earth's crust, uranium is around 500 times more abundant than gold

THE BEST PROTECTION

How nuclear protection suits help prevent radiation causing havoc in the human body

1 RESPIRATOR
Suits are fitted with respirators to supply the wearer with clean air and filter out any potential radioactive dust.

3 FACE GUARD
A face shield is used to prevent radioactive dust or low-energy radiation such as alpha or beta radiation making contact with the head or face.

6 GLOVES
Radiation-resistant gloves are used to protect the wearer while handling potentially contaminated items.

5 MATERIAL
Suits specifically designed to block radiation often use either boron or lead-based materials, which naturally prevent alpha and beta radiation from penetrating the suit.

2 DOSIMETER
A dosimeter is a small device that measures the level of surrounding ionising radiation, such as gamma rays, which the suit can't protect against.

4 RUBBER BOOTS
Thick rubber boots stop any radioactive chemicals or debris from leaking into the suit.

A radiographer wearing protective clothing during World War I, circa 1918

5 FACTS WHO NEEDS PROTECTION?

1 DOCTORS
Medical staff using radiation-emitting devices such as X-ray machines use lead body shielding to protect their vital organs during a procedure.

2 FIREFIGHTERS
First responders to fires at buildings that house radioactive materials, such as blood banks, hospitals and energy plants, require radiation suits for protection.

3 MILITARY
When responding to chemical, biological, radiological and nuclear (CBRN) situations during warfare or conflicts, military personnel require physical protection from any potentially radioactive sources.

4 NUCLEAR EMPLOYEES
Radioactive sources are used to produce energy through nuclear fission reactions. In the event of a risk of high exposure, employees at nuclear power plants require access to protective clothing.

5 RESEARCHERS
Conducting experiments and investigating the physical properties and technologies around radioactive sources requires the use of radiation suits in some cases.

© Getty / NASA / Wiki: H. J. Hickman

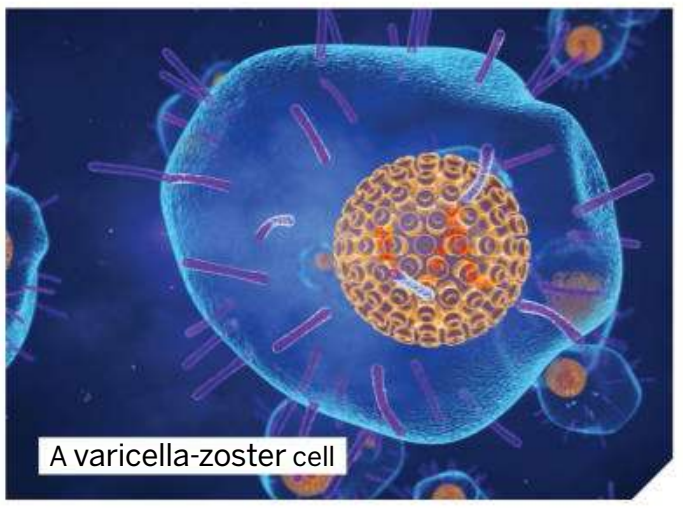
WHAT IS SHINGLES?

This painful rash is the result of a lingering virus

WORDS **AILSA HARVEY**

Shingles is a viral infection that can emerge anywhere on the body in the form of a painful, blistering rash. Usually, the rash forms as a stripe that wraps around one side of the body. What makes this viral infection different from many others that you may have experienced is that you don't contract the virus immediately prior to getting shingles symptoms. Instead, it has been living inside you, and could have been there for many decades. This is because shingles is a result of the varicella-zoster virus – the same one that causes chickenpox.

Rather than completely flushing the virus from your body when you overcome chickenpox, some of it stays in your nerves, dormant and unproblematic. When your body is busy fighting another illness or condition, or as your immune system weakens with age, the virus is more likely to reactivate and resurface. The varicella-zoster virus travels along nerve paths to reach the skin and create the nasty rash we call shingles.



A varicella-zoster cell

The shingles rash commonly stretches around one side of the torso

IS SHINGLES CONTAGIOUS?

The varicella-zoster virus is highly contagious between people who have not been exposed to it yet and is spread through direct contact with the fluid from the rash's blisters. However, if you have already contracted chickenpox, you won't get symptoms from being in contact with someone with shingles. Those who contract the virus for the first time from someone with shingles won't catch shingles, but will flare up with chickenpox instead.

Many purposely expose their children to the varicella-zoster virus, and even host 'chickenpox parties' when a child has the symptoms so that others can catch it too. This is because the symptoms of the virus are usually much more mild when exposed at a young age, and you can only contract the virus in its chickenpox form once.

SHINGLES IN THE NERVES

How this virus makes a comeback

1 CHICKENPOX EXPOSURE
Most people are exposed to chickenpox at a young age, causing an itchy rash across the whole body.

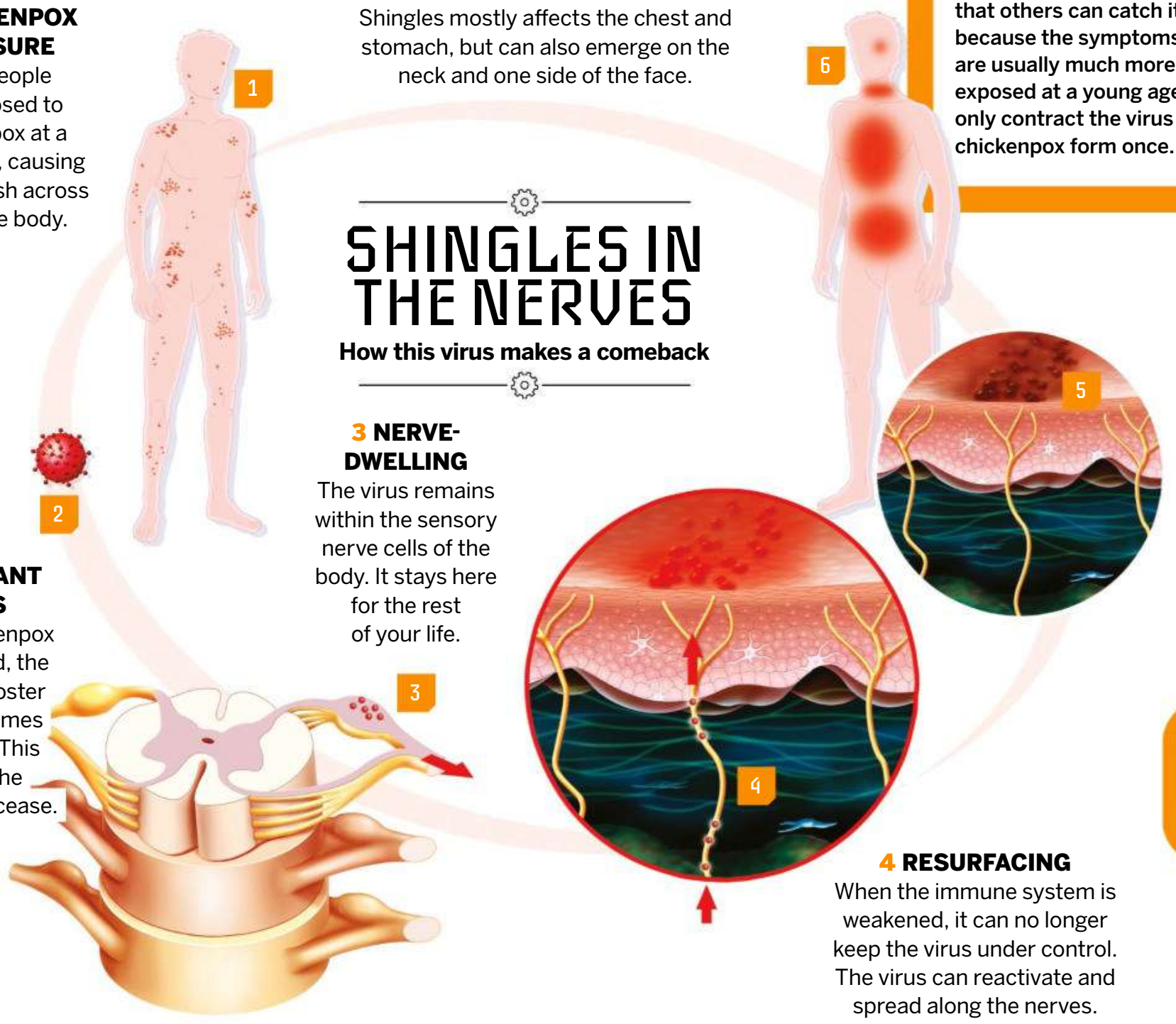
2 DORMANT VIRUS
After chickenpox has cleared, the varicella-zoster virus becomes dormant. This means the symptoms cease.

3 NERVE-DWELLING
The virus remains within the sensory nerve cells of the body. It stays here for the rest of your life.

4 RESURFACING
When the immune system is weakened, it can no longer keep the virus under control. The virus can reactivate and spread along the nerves.

5 SHINGLES SYMPTOMS
The varicella-zoster virus returns, with more severe symptoms. The painful rash is usually confined to specific areas of the body.

6 AFFECTED AREAS
Shingles mostly affects the chest and stomach, but can also emerge on the neck and one side of the face.



Did you know?

Around half of people who live to 85 will experience shingles

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SPIES IN THE SKY

From balloons to satellites, Earth is under constant surveillance from above

WORDS **ANDREW MAY**

DID YOU KNOW? Super-stealthy spy drones played a key role in locating the fugitive Osama bin Laden in 2011

The topic of high-altitude surveillance hit the headlines in February this year, with the shooting down of what appeared to be a Chinese spy balloon by a US fighter plane. The balloon was large enough that it was easily visible from the ground, but in more subtle ways – using satellites, stealth planes and drones – covert observation from above is going on all the time, and has been for years.

The military value of large, crew-carrying balloons was recognised almost as soon as they were invented. They were employed during the French Revolutionary Wars of the 1790s, and again in the American Civil War of the 1860s, to gather valuable information about enemy activity that couldn't be observed from ground level. Similarly, when powered aircraft were first used during World War I, one of their main roles was in the reconnaissance of enemy lines – initially using an observer with binoculars, and later employing cameras that took the first aerial photographs. By World War II, with the aid of onboard film-processing equipment, it was possible to analyse high-resolution images of the ground below in near real time.

Then, during the Cold War that followed, the looming threat of nuclear conflict between East and West saw high-altitude surveillance take on a crucial new role. It was no longer a matter of observing troop movements during wartime, but of monitoring weapon development during an uneasy peace. The need to do this as unobtrusively as possible saw the development of two new technologies: Earth-orbiting satellites and ultra-high-flying spy planes. A pioneer in the latter category was America's Lockheed U-2, which demonstrated both the strengths and weaknesses of undertaking covert reconnaissance over hostile territory. During 1962, a U-2 secretly photographed nuclear missile sites being built by the Soviet Union on the island of Cuba, dangerously close to the US mainland. By exposing the missile bases before they were finished, the U-2 images may well have averted an intended nuclear attack. But overflights of enemy territory had their disadvantages, too – as was seen in 1960 when a U-2 flown by Central Intelligence Agency (CIA) pilot Francis Gary Powers was famously shot down over the Soviet Union, resulting in a huge diplomatic embarrassment for the United States.

> "Covert observation from above is going on all the time, and has been for years"

Powers' reconnaissance flight over the Soviet Union was illegal under international law, but the same isn't true of satellites in orbit around the Earth. The basic physics governing orbital motion makes it almost impossible to prevent a satellite passing over any given country, so from the very beginning of the Space Age the international community has accepted the principle of the 'freedom of space'. This means that, unlike spy planes, spy satellites are perfectly legal whatever country they fly over. Satellites have other advantages, including being much harder to shoot down. Because they are uncrewed this doesn't put personnel at risk of injury or capture. As a result, from the early 1960s onwards satellites increasingly became the military's technology of choice for aerial surveillance.

Even so, spy satellites have their limitations. In movies they're often portrayed as virtually omniscient, providing real-time imagery from directly overhead whatever location is of current interest. In reality, however, they're whizzing around Earth at high speeds, only fleetingly over any particular area, and often viewing it slantwise. That's why countries still need to supplement satellite data with other technologies such as drones – which can loiter unobtrusively over an area of interest for several hours – and even balloons.

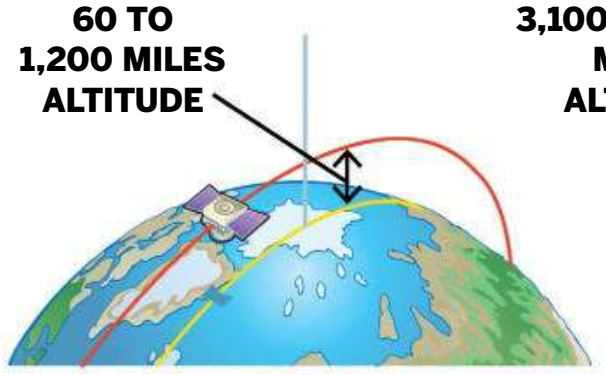
The U-2 spy plane could fly at 13.2 miles altitude, higher than most aircraft

© Getty

MILITARY SATELLITES

Military intelligence gathering can be divided into the two categories of surveillance, meaning the continuous monitoring of a location of interest and reconnaissance, or the collection of data in support of a specific operation. Satellites can help with both of these. There are four types of spy satellite: the first to monitor enemy missile launches, the second to detect nuclear explosions, the third to collect photographic or radar imagery and the fourth to intercept electronic communications and other transmissions .

The coverage and performance of an Earth-observing satellite will depend on its particular orbit. In very broad terms, most satellites are either in low-Earth orbit at an altitude of a few hundred miles, or in a much higher geosynchronous orbit, around 22,000 miles above Earth's surface. Satellites in the latter category have the special property that they orbit at the same rate that Earth itself revolves – once every 24 hours – and so effectively remain stationary over the same spot on Earth's surface. This makes the geostationary orbit useful for certain types of spy satellites, such as the US National Reconnaissance Office's Signals Intelligence (SIGINT) satellites, designed to eavesdrop on electronic communications. On the other hand, geostationary orbit is much too far from the ground to produce high-resolution images of it, whether using optical or radar technology. For these applications, orbits should be as low as possible, perhaps as little as 120 miles above Earth's surface.


60 TO 1,200 MILES ALTITUDE
LOW EARTH ORBIT LEO
3,100 TO 6,200 MILES ALTITUDE
MEDIUM EARTH ORBIT MEO
22,300 MILES ALTITUDE
GEOSTATIONARY ORBIT GEO

Both geosynchronous and low-Earth orbits have their uses for spy satellites

THE SPY BALLOON

In January and February 2023, a big white balloon was seen flying east at high altitude across North America. At one point it flew close to Malmstrom Air Force Base in Montana, where several highly sensitive nuclear missile silos are located. The Chinese government confirmed the balloon originated there, but claimed it was a civilian weather balloon that had strayed off course. The sophisticated equipment the balloon was seen to be carrying led the US to conclude that it was on a spying mission, and it was shot down. A particularly unusual feature was the apparent presence of propellers to control the direction of flight, which are not needed by ordinary weather balloons.

A photograph of the Chinese balloon taken by a member of the public

GOOGLE EARTH

Earth-observing satellites have other uses besides spying, including crucial ones such as tracking climate change, locating previously unknown ecological features and recording the unfolding history of our planet. One of the most widely used tools in this area is Google Earth, which employs composite imagery from a variety of sources to form a comprehensive, interactive map of Earth. Launched in 2005, Google Earth now embodies some 24 million satellite photos collected over the past four decades, representing a collaboration between Google, NASA, the European Space Agency and the US Geological Survey. Imagery comes from a range of sources, including the European Sentinel satellites, as well as American Landsat, Terra and Aqua satellites. The most powerful to date is the WorldView-3 satellite, launched by the private company DigitalGlobe in 2014, which provides imagery that is twice as sharp as its predecessors.

The motorhome-sized WorldView-3 satellite can see objects as small as 30 centimetres across

ANTI-SATELLITE TECHNOLOGIES

CO-ORBITAL SATELLITE
These are weapons that are placed in a similar orbit to the target, then manoeuvre close to it before attacking, either by crashing into it or using robotic arms.

DIRECT ASCENT WEAPON
These are conventional missiles that are launched either from Earth's surface or from an aircraft to destroy a satellite target as it passes overhead.

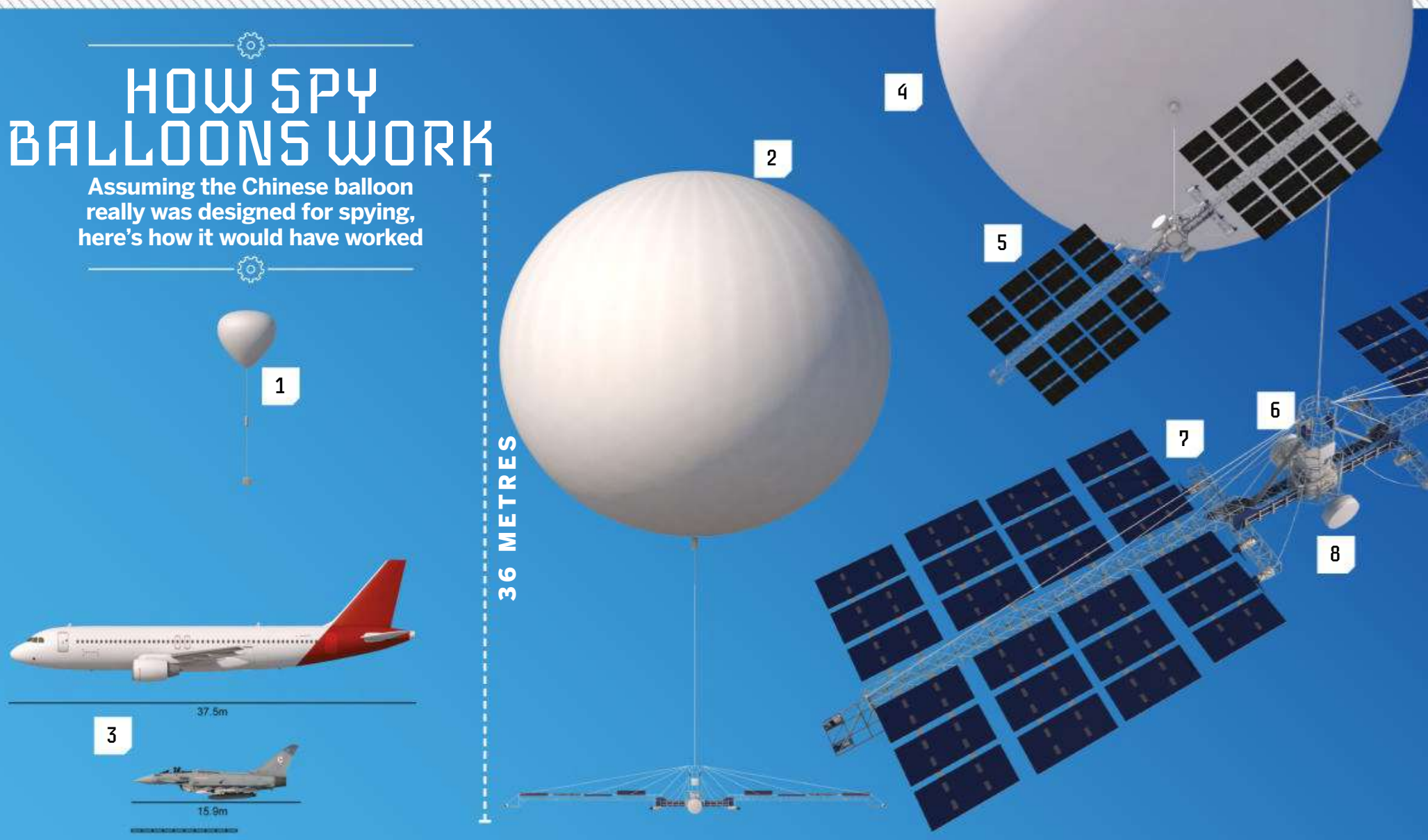
LASER WEAPON
Unlike their science-fiction counterparts, real-world laser weapons aren't designed to blow up enemy satellites, but to disable their electronics by heating them to a high temperature.

CYBER ATTACK
The easiest way to neutralise a satellite is to prevent it from communicating with ground stations on Earth, for example by jamming its radio signal.

DID YOU KNOW? Spy satellites travel on highly predictable orbits, so it's easy to hide from them as they pass overhead

HOW SPY BALLOONS WORK

Assuming the Chinese balloon really was designed for spying, here's how it would have worked



1 WEATHER BALLOON
Typically, these last a few hours, travel a hundred miles at most and burst when they reach 11.3 miles altitude.

2 SPY BALLOON
This stayed airborne for several days, travelled thousands of miles and was observed at altitudes up to 12.3 miles.

3 ORDINARY AIRCRAFT
Commercial airliners typically fly at an altitude of 7.6 miles or less, although military jets can reach 12.3 miles.

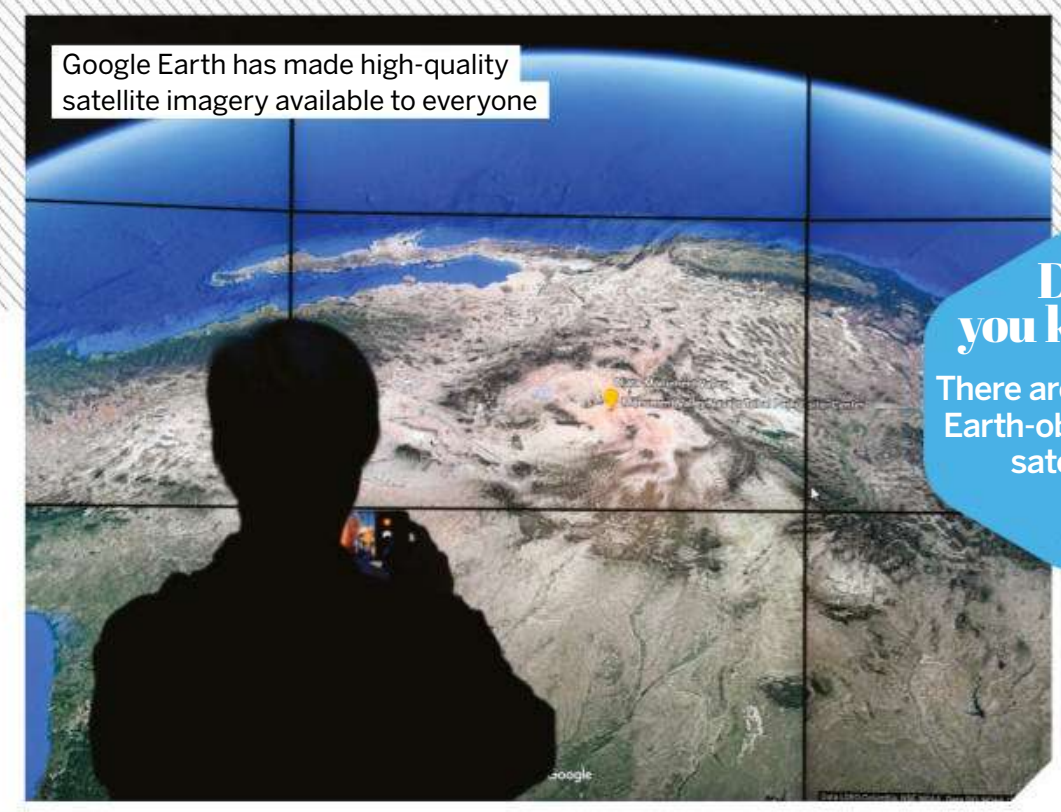
4 GIANT-SIZE BALLOON
The helium-filled balloon and the payload suspended beneath it had a total height of around 36 metres.

5 SOLAR PANELS
The balloon's payload received its power from a huge array of solar panels, making it look rather like a satellite.

6 SURVEILLANCE PAYLOAD
This was likely to consist of a number of downward-looking cameras, radars and other sensors.

7 PROPELLERS
Unlike most balloons, which drift wherever the wind takes them, this one could control its route using propellers.

8 COMMUNICATION DISH
Like a satellite, the balloon was equipped with a radio transmitter to send data back to its operators.


Google Earth has made high-quality satellite imagery available to everyone

Did you know?

There are over 900 Earth-observation satellites

The Vought ASM-135A anti-satellite weapon was the only US air-launched missile to bring down a satellite

© Alamy / Getty / U.S. Air Force / ESA / Wiki: Russotp / Illustration by Adrian Mann

The KH-9 was 16 metres long and over 11 tonnes in mass

COLD WAR SPY SATELLITE

When spy satellites were first developed in the 1960s, their designers were faced with a serious problem due to the limited technology available at the time. In the pre-digital age, the only way to transmit images electronically was via an analogue TV signal, which had very poor spatial resolution. A typical TV system of that time employed a mere 405 scanning lines with 720 samples per line, giving an effective resolution of less than 0.3 megapixels. That's far inferior to the 20 megapixels provided by professional photographic film of the same era. The upshot was that to obtain images of acceptable quality, spy satellites had to use a film camera, and the resulting film then had to be physically returned to Earth for processing and interpretation.

The film-based spy satellite reached its zenith with the massive KH-9 Hexagon, the final generation of such satellites produced by the US. Popularly known as 'Big Bird', it remained a mainstay of US intelligence gathering from the early 1970s to the mid-1980s, providing aerial imagery that combined a high resolution with wide coverage. Over the course of 19 missions, KH-9 satellites imaged no less than 877 million square miles of Earth's surface.

INSIDE THE BIG BIRD

The KH-9 was the most sophisticated film-based camera ever launched into space

6 MAPPING CAMERA
Later missions included this secondary camera, which took very wide-angle photos for mapping purposes.

1 SOLAR PANELS
At the rear of the satellite, a pair of deployable solar panels provided power for the electrical systems.

5 RE-ENTRY VEHICLES
There were four of these, which stored film from the cameras and subsequently returned it to Earth.

4 MAIN CAMERA
This was a sophisticated system that took stereo images using both forward-looking and rear-looking optics.

2 SATELLITE CONTROL SECTION
Containing a hydrazine-powered propulsion system, this enabled the satellite to manoeuvre in orbit.

3 FILM SUPPLY SECTION
Like any other film camera of its era, the KH-9 had a spool of film that unrolled as it was used.

SPY TIMELINE

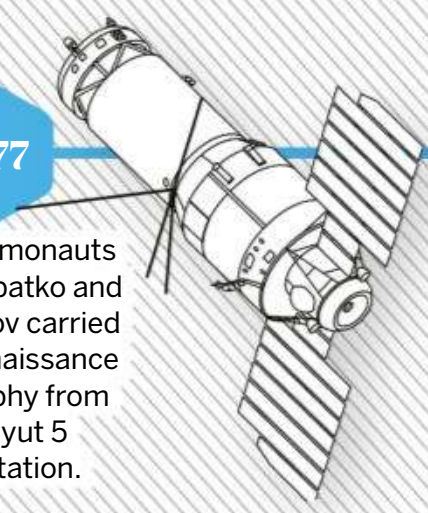
1954
Following a feasibility study, the US Air Force began planning its first reconnaissance satellite project.

1960
The first operational spy satellite, America's Discoverer 14, successfully obtained an image of a Soviet air base.

1962
Successful launch and recovery of the first Soviet 'Zenit-2' spy satellite, based on Yuri Gagarin's Vostok capsule.

1971
Launch of the first of America's huge KH-9 reconnaissance satellites; this preliminary mission lasted seven weeks.

1977
Soviet cosmonauts Viktor Gorbatko and Yuri Glazkov carried out reconnaissance photography from the Salyut 5 space station.



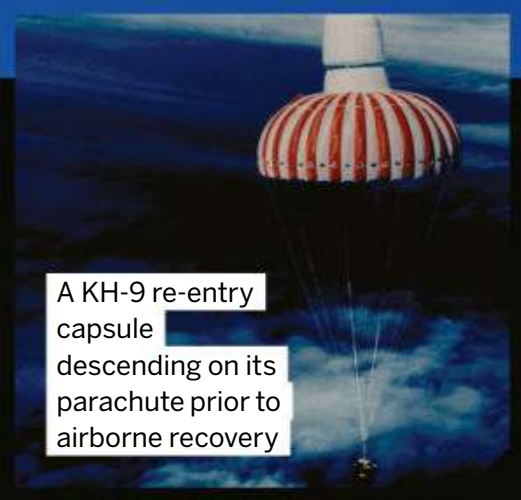
DID YOU KNOW? NASA's planned Roman Space Telescope will be built around recycled parts from an unwanted spy satellite

A TYPICAL KH-9 MISSION

Launched like any other satellite, the way the film was returned to Earth was unique

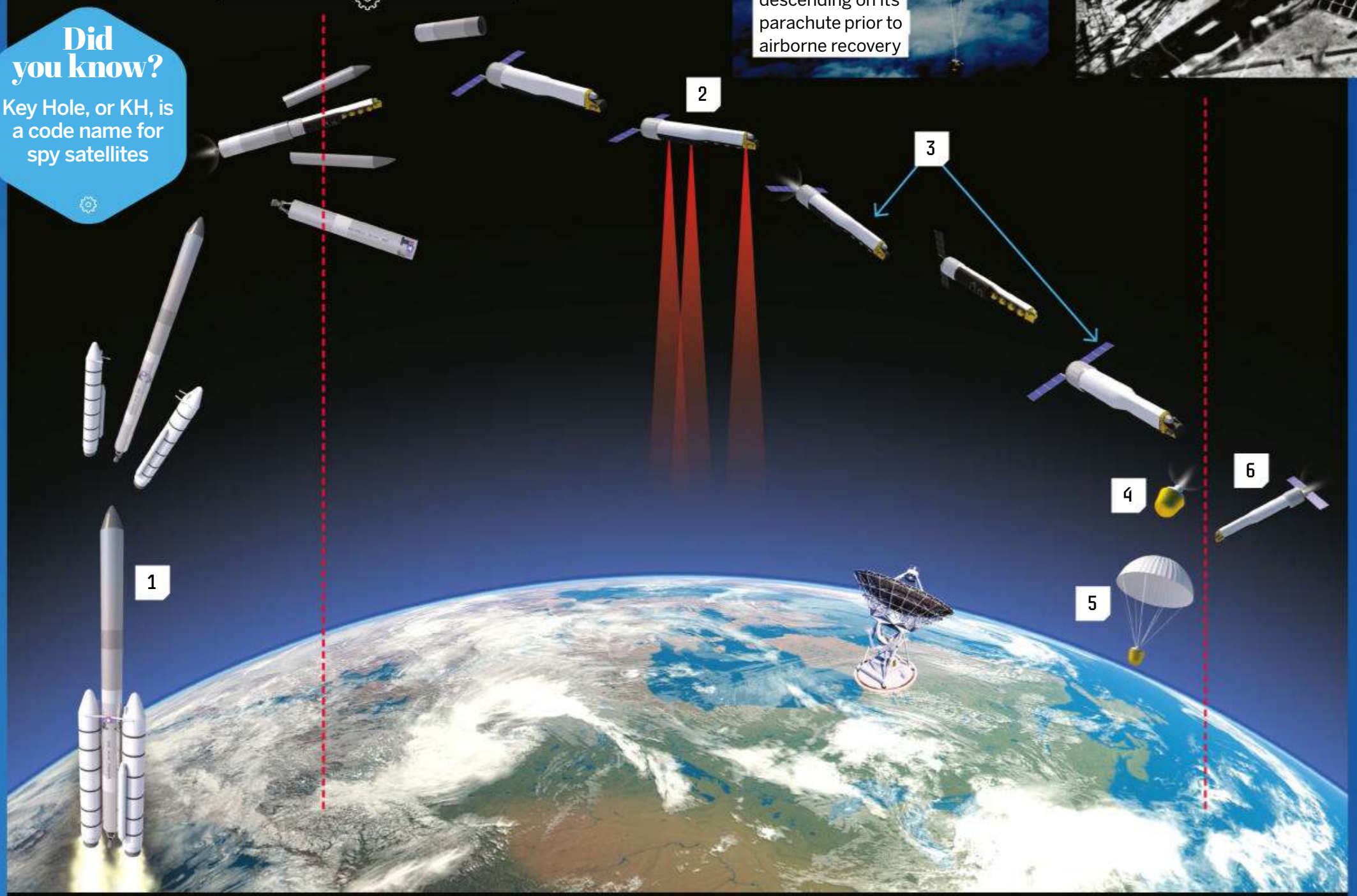
Did you know?

Key Hole, or KH, is a code name for spy satellites



A KH-9 re-entry capsule descending on its parachute prior to airborne recovery

A photograph taken by a KH-9 satellite in 1972 of the Soviet launch site at Baikonur



1 LAUNCH
The satellite was launched into space by a Titan IIID rocket.

2 SURVEILLANCE OPERATIONS
Over the course of many orbits, the satellite took detailed photographs of the ground below.

3 RELEASE OF CAPSULES
When a capsule had used its film up, the satellite manoeuvred to release it onto a re-entry trajectory.

4 CAPSULE DESCENT
On release, it descended towards a carefully chosen location over the US or in international waters.

5 RECOVERY
The capsule, descending slowly by parachute, was caught in mid-air by a US aircraft.

6 SATELLITE DE-BOOST
After all the capsules had been returned to Earth, the remaining satellite was 'de-boosted' out of orbit.

1988
The crew of Space Shuttle flight STS-27 manually deployed the first in a series of new radar-equipped spy satellites.

1991
Operation Desert Storm – the liberation of Kuwait – saw the first full-scale military use of space-based assets to coordinate an operation.

2008
A US missile was used to destroy one of the country's own spy satellites, which malfunctioned after it reached orbit.

2018
A latecomer to the field, the UK launched its first spy satellite, the Royal Air Force's Carbonite-2.

2019
The US created a new military branch, the US Space Force, to oversee all of its military activities in space.

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WEIRD CREATURES OF THE DEEP

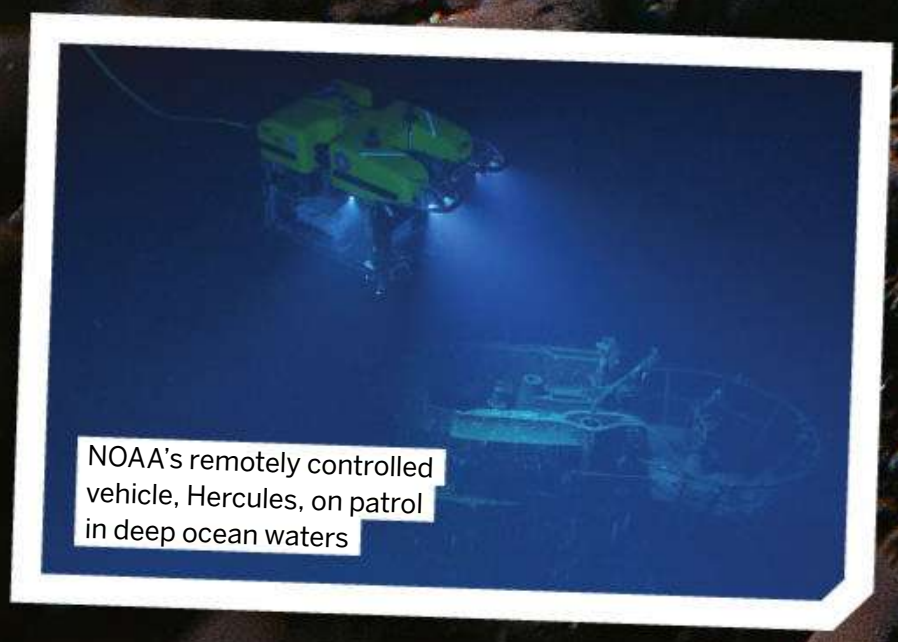
Meet the strange and wonderful animals living thousands of metres below the surface of our oceans

WORDS SCOTT DUTFIELD

More than 80 per cent of the world's oceans are yet to be explored and mapped, meaning there's a lot we don't know about what lies beneath the surface. To say that the world's oceans are vast would be an understatement. Around 79 per cent of the entire biosphere of our planet is made of water that's 1,000 metres deep, and the place where the ocean reaches its deepest point is seven miles from the surface. Known as the Mariana Trench, this is a crescent-shaped trough that runs for more than 1,550 miles along the length of the Western Pacific Ocean.

It was first discovered in 1875 by HMS Challenger after sailors dropped a weighted rope about five miles into the ocean. In 1951, HMS Challenger II returned to the same spot and determined that there were two more miles to go before reaching the bottom. In 2012, *Titanic* director James Cameron descended to the Mariana Trench in a one-person submarine called Deepsea Challenger and spent four hours at a depth of seven miles below the surface, witnessing the deepest waters on Earth.

Life in the deep ocean exists in one of two places: the benthic zone or the pelagic zone.

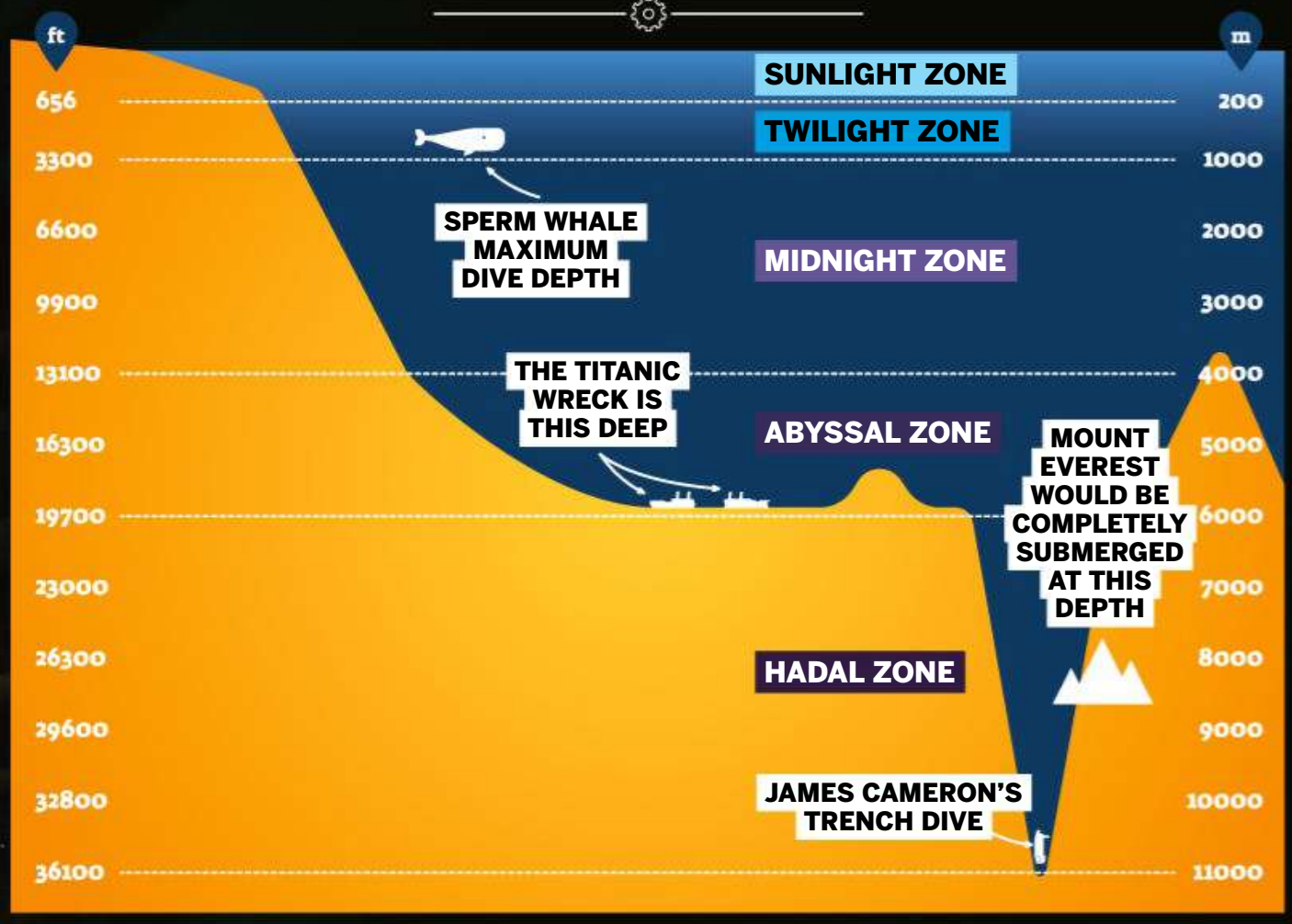


NOAA's remotely controlled vehicle, Hercules, on patrol in deep ocean waters

DID YOU KNOW? It took over two hours for Deepsea Challenger to reach the Mariana Trench

OCEAN ZONES

How the world's waters are divided into layers



SUNLIGHT ZONE
SURFACE TO 200 METRES
The uppermost layer of the ocean and the extent at which most of the Sun's light can penetrate the water.

TWILIGHT ZONE
200 TO 1,000 METRES
The most dramatic changes in water temperature occur in this zone.

MIDNIGHT ZONE
1,000 TO 4,000 METRES
The only light seen in this zone comes from the bioluminescence of deep-sea fish and invertebrates.

ABYSSAL ZONE
4,000 TO 6,000 METRES
The near-freezing temperatures of this zone mean few species live within it.

HADAL ZONE
6,000 TO 10,935 METRES
The final and most extreme environment in the ocean. The pressure of the water above the Mariana Trench is 1,088 times that at surface level.

The benthic zone refers to the sedimented bottom or seafloor, whereas the pelagic zone is everywhere else – the open water of the ocean. These two general zones have subzones within them that describe the layers of the ocean moving down towards the deepest point on the planet, the Mariana Trench. Beyond the uppermost layer of the ocean, known as the epipelagic or sunlight zone, life has evolved to adapt to life in the cold, dark extremes of the deep sea.

One of the most notable differences between epipelagic animals and deep-sea creatures is the abundance of bioluminescent biology. For deep-ocean creatures, hunting and finding a mate can be hard enough during daylight, but in a world where light is absent, animals such as angler fish (*Lophius piscatorius*) rely on generating their own light source to attract prey or to communicate with other members of their species.

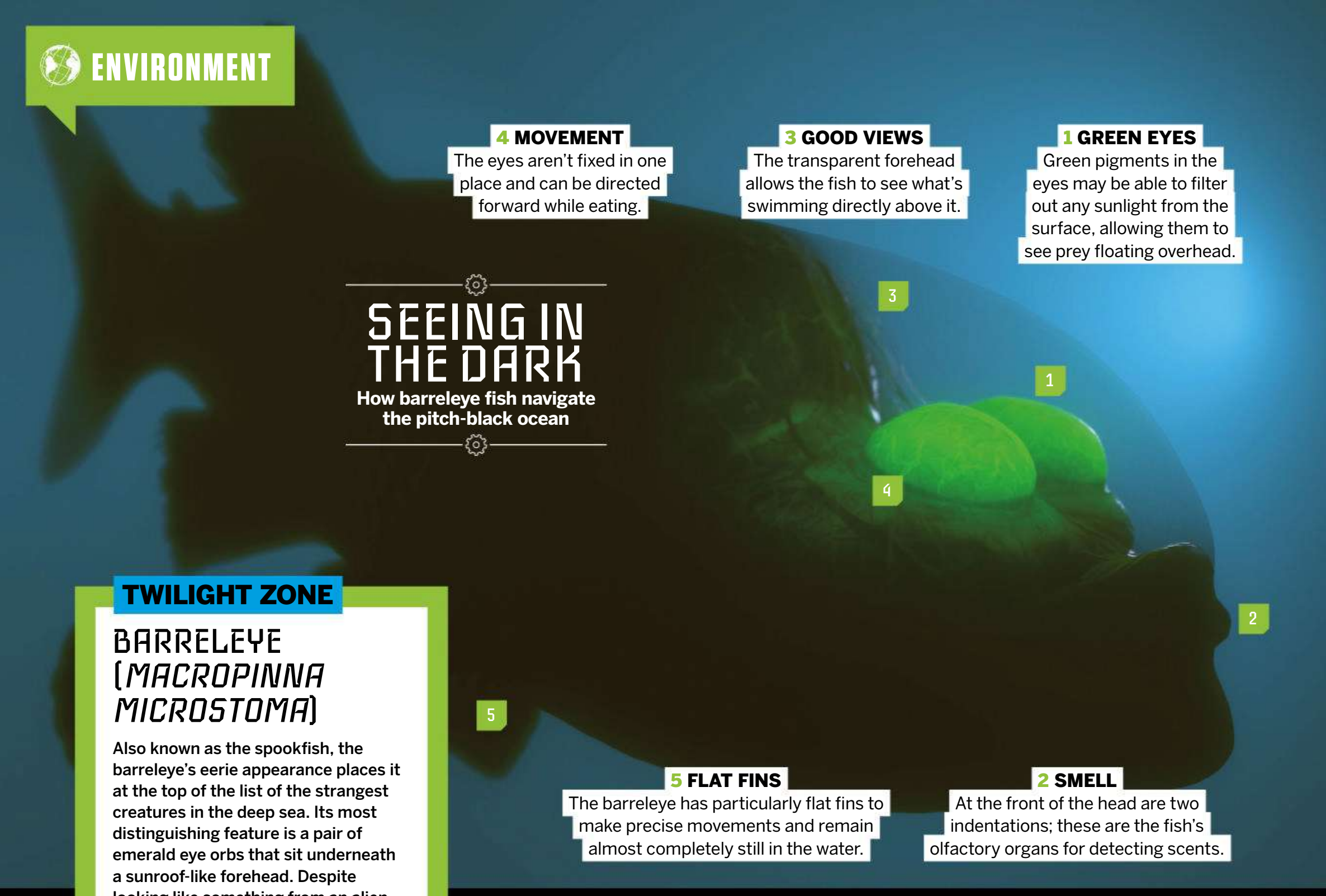
Did you know?
The deepest point any fish has been found is 8,372 metres

To seek out undiscovered deep-sea creatures, several institutions around the world, such as the National Oceanic and Atmospheric Administration (NOAA), have employed deep-sea submarines and underwater rovers to trawl the ocean's depths in the hunt for new life forms. Submersible remotely operated vehicles (ROVs), such as NOAA's Hercules, take snapshots of life in the deep sea as they descend through the water column to the seafloor. Some crewed vehicles, such as the Woods Hole Oceanographic Institution-operated rover named Alvin, have been in operation since 1960 and can descend to great depths of 4,500 metres to witness the weird and wonderful life forms that call the deepest reaches home.

© Getty / Ocean Exploration Trust/Nautilus Live

SEEING IN THE DARK

How barreleye fish navigate the pitch-black ocean



4 MOVEMENT
The eyes aren't fixed in one place and can be directed forward while eating.

3 GOOD VIEWS
The transparent forehead allows the fish to see what's swimming directly above it.

1 GREEN EYES
Green pigments in the eyes may be able to filter out any sunlight from the surface, allowing them to see prey floating overhead.

5 FLAT FINS
The barreleye has particularly flat fins to make precise movements and remain almost completely still in the water.

2 SMELL
At the front of the head are two indentations; these are the fish's olfactory organs for detecting scents.

TWILIGHT ZONE

BARRELEYE (*MACROPINNA MICROSTOMA*)

Also known as the spookfish, the barreleye's eerie appearance places it at the top of the list of the strangest creatures in the deep sea. Its most distinguishing feature is a pair of emerald eye orbs that sit underneath a sunroof-like forehead. Despite looking like something from an alien planet, the barreleye's unique appearance serves a purpose. In a similar way to how sunglasses filter out sunlight, the barreleye's green-tinted eyes can block out any ambient light to reveal potential prey swimming overhead. Hunting is made all too easy by their transparent forehead, which allows for a better view overhead. Researchers have also suggested that these fish can distinguish between sunlight and the natural bioluminescence that some species emit.

The barreleye mainly feeds on crustaceans, zooplankton and siphonophores – jelly-like colonies of individual organisms. Some studies have suggested that barreleye fish may also swim through the tentacles of siphonophores and pick off prey such as crustaceans that have become entangled in the siphonophore's grasp, stealing a meal. These fish have proved elusive to researchers, who hope to better understand their biology and behaviour: despite first being described in 1939, there have only been nine recorded encounters.

Did you know?

It takes sea snails 45 minutes to eat a meal

TWILIGHT ZONE

FLYING SPAGHETTI MONSTER (*BATHYPHYSA CONIFERA*)

This creature looks more like a mass of matted hair dredged from a shower plug, but this mess of an animal is actually a community of organisms that collectively form a structure called a siphonophore. Much like the community that produces corals, siphonophores are composed of tiny multicellular organisms called zooids. Each zooid plays a different role in the siphonophore commune – some zooids are built to hunt, while others are only able to reproduce new zooids. Together, zooids create two halves of the overall siphonophore. The upper half of the spaghetti monster is dedicated to a gas-filled structure called a pneumatophore, for mobility, whereas the lower portion consists of noodle-like structures filled with gastrozooids to catch and digest food. The collective spaghetti monster organism can reach enormous lengths, with some specimens measuring up to 40 metres long.

Catching sight of the flying spaghetti monster isn't common. It was first seen in 1878 when German trawlers got one stuck in their fishing nets, but due to its preference for the deep sea, only a handful of sightings have been recorded.

An artist's illustration of a flying spaghetti monster swimming through the ocean

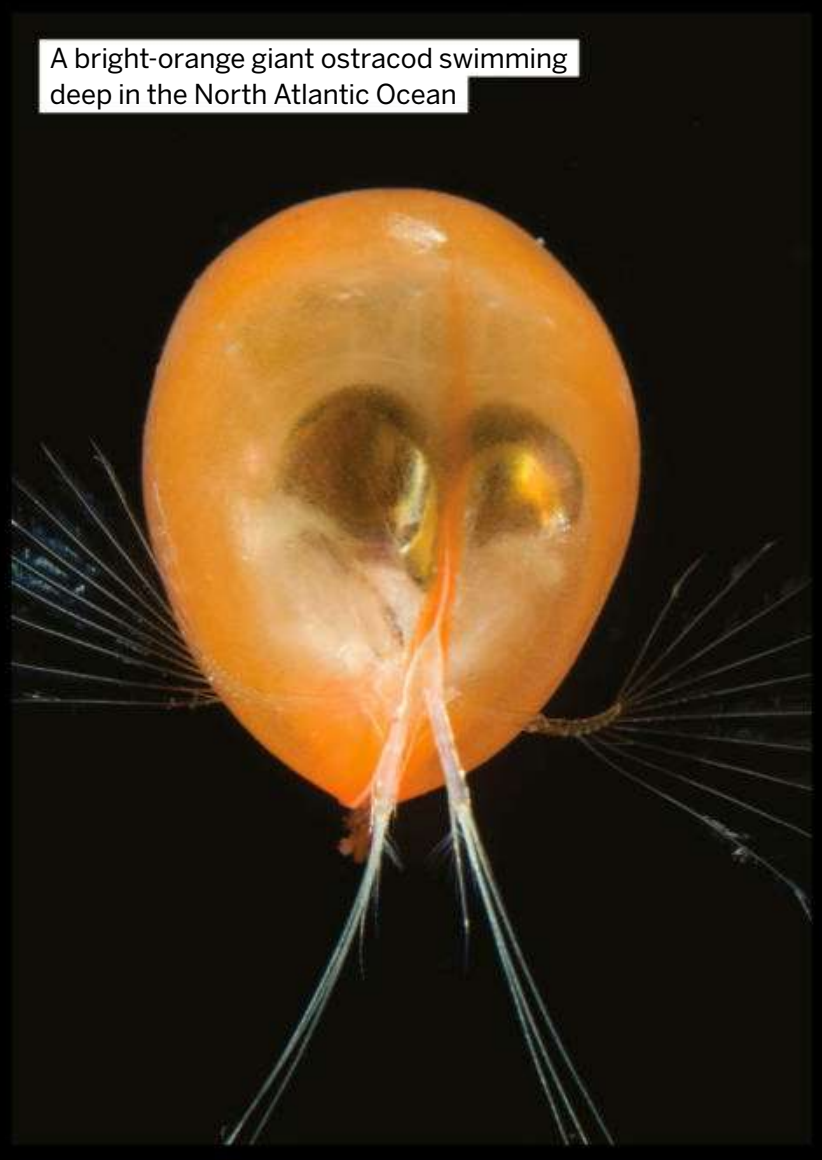
DID YOU KNOW? The deepest recorded whale dive was made by a Cuvier's beaked whale, reaching 2,992 metres

TWILIGHT ZONE

GIANT OSTRACOD (*GIGANTOCYPRIS AGASSIZII*)

At first glance it might look like a piece of corn lost in the ocean, but this is a tiny invertebrate, sometimes known as a seed shrimp. Although it might be giant in name, the seed shrimp is only around 2.5 centimetres in size. Much like a clam, these crustaceans live in a hinged spherical shell. When the bubble-like shell is open they extend feather-like appendages that act like nets to catch any passing fish larvae or tiny worms.

Seed shrimp are well adapted to life in the dark and use a pair of mirrored eyes to detect the slightest glint of light from potentially glowing prey. These tiny giants wait around for food to find them and spend their time searching the ocean zones between 600 and 2,300 metres deep to hunt for food.



A bright-orange giant ostracod swimming deep in the North Atlantic Ocean

HADAL ZONE

SEA SPIDERS (*PYCNOGONIDA*)

The deepest, darkest regions of the ocean have spawned some of the most freaky animals, and sea spiders are no exception. Sea spiders come in all shapes and sizes, from rice-sized spiders to 50-centimetre invertebrates. They spend their time trawling the deepest ocean floors looking for soft-bodied animals such as jellyfish, coral and anemones, which they devour using their tubular mouths. Although they look like they belong to the arachnid family, sea spiders are instead pycnogonids, ocean insects of 1,300 different species. If a spider, crab and starfish could all make a baby, it might look something like a sea spider. Each spider has eight legs, a hard exoskeleton and a pair of claws, and its vital organs run through all its legs.

A sea spider crawling along the seafloor at Komodo National Park

5 STRANGE JELLYFISH

1 ATOLLA JELLYFISH (*CORONATE MEDUSA*)
Also known as the alarm jellyfish, these vibrant-red creatures live thousands of metres from the surface where red light can't penetrate, thus making them appear almost invisible.

2 COMB JELLYFISH (*CTENOPHORES*)
Found in waters around the world at nearly all depths, these versatile jellyfish use beating rows of cilia, which have the appearance of the teeth of a comb, to paddle through the water.

3 *HYDROMEDUSAE*
These robust jellyfish are found throughout the ocean zones and have a life cycle that starts as a bottom-dwelling polyp before blooming into a free-swimming adult.

4 GIANT PHANTOM JELLYFISH (*STYGIOMEDUSA GIGANTEA*)
Over ten metres long, these mysterious jellyfish have billowing ribbon-like 'mouth arms' which are believed to entangle prey and deliver them to the mouth.

5 HELMET JELLYFISH (*PERIPHYLLA PERIPHYLLA*)
These jellyfish use a sensory organ bulb that can detect a change in light. When they sense light, they retreat deeper into the ocean for protection.

© alamy / Getty

A specimen of Lavenberg's gulper eel showing the huge mouth hinge used to gobble prey

MIDNIGHT ZONE

LAVENBERG'S GULPER EEL (*SACCOPHARYNX LAVENBERGI*)

Food is far from abundant for many living in the midnight zone, so some fish have adapted to take full advantage when a meal crosses their path. For the gulper eel, this means evolving an enormous mouth that helps it swallow every last bite. Also known as the pelican eel, these hungry fish deploy a fleshy net to scoop up shrimp, squids and crustaceans. However, the chance of stumbling across food is slim, so gulper eels shine a little pinkish light near their rear fin to entice potential prey their way. It's not just food that gulpers need to find, but also a mate. Without the ability of sight to find a future partner, male gulper fish develop a large olfactory organ to sniff out females. However, it comes at a cost, and they lose their teeth in the process.

ABYSSAL ZONE

DRAGON FISH (*STOMIIDAE*)

These fish are formidable predators. Swimming thousands of metres from sunlight, dragon fish have evolved skin with the darkest black pigments seen in nature. This makes them nearly invisible in the abyssal zone, perfectly hidden from unsuspecting prey. Some species of dragon fish use a luminescent lure, similar to angler fish, to entice prey closer before snatching them with their large teeth. Researchers have also discovered that their teeth are covered in nanocrystals. A nanocrystal coating prevents any bioluminescent light from reflecting off them, which would alert prey to what lurks in the shadows. The nanocrystals also strengthen the teeth to ensure success in a single bite.

Although these pencil-sized predators typically hang out in the abyssal zone, female dragon fish will ascend from the depths of the ocean to the surface in times when food is scarce. The males stay firmly in the deep, relying on their lures to attract attention.

A Pacific blackdragon (*Idiacanthus antrostomus*) lurking in the deep sea

MIDNIGHT ZONE

ZOMBIE WORMS (*OSEDAX ROSEUS*)

Rather than feasting on the brains of other animals – as their name might have you believe – these worms prefer to dine on the fat and protein within the bones of the dead. This deep-sea delicacy is quite the undertaking for these mouthless worms. To 'eat' the fat, zombie worms secrete an acid from their skin to first dissolve the bone. A symbiotic bacteria living in the worm's body then digests and extracts the nutrients from the fat and protein and shares them with the host worm.

All the worms seen snacking on dead animal bones on the seafloor are females. Males, on the other hand, can only be spotted through a microscope and live in groups inside the bodies of the females. The purpose of this internal gathering is to ensure successful reproduction in an environment where locating a mate is difficult.

Zombie worms have been found munching on the bones of different marine creatures like whales and fish

Did you know?

The largest recorded bigfin squid was 6.4 metres long

DID YOU KNOW? More than 60 per cent of Earth is covered in water a mile deep

ABYSSAL ZONE

SWIMMING SEA CUCUMBER (*ENYPNIASTES EXIMIA*)

Meet the gelatinous floating digestive system that drifts through the ocean's abyss feeding on sand. Unlike other species of sea cucumber, which are bound to the benthic zone, this 'swimming' variety can search the seafloor and evade potential predators using its webbed cowl. The cowl moves in an undulating motion to row the creature through the ocean. For sustenance, these sea cucumbers float above the sandy, silty seafloor, vacuuming sediment as they go. Within the fine grains of sand are even finer pieces of biological debris commonly known as marine snow. This deep-sea delicacy is predominantly made up of phytoplankton that sink to the floor, collecting fish faeces, decaying material and other organic matter along the way.

This nutritious meal is all they need to feast on for survival. As a relatively defenceless creature, this sea cucumber has evolved the ability to light up parts of its body that are fragile and easily flaked off to distract any potential predators and give them time to escape.

Swimming sea cucumbers are sometimes called pink sea-through fantasia for their vibrant appearance

1 MINI FEET
12 tube-like feet are used to manoeuvre along the seafloor and pick up sediment.

2 WINGS
20 webbed tentacles act as the cucumber's wings to propel it through the water.

3 DIGESTIVE TRACT
Due to their transparent body, their coiled gut is prominently on show.

4 WATER RETENTION
The majority of its body is filled with water to keep the cucumber buoyant.

5 CLEAN POOP
Once these sea cucumbers have stripped sediment of tasty debris, they deposit the clean sediment from their anus.

INSIDE A SEA CUCUMBER

How these oddities of the ocean survive in the deep

Sea angels are a type of sea slug

TWILIGHT ZONE

SEA ANGELS (*GYMNOSOMATA*)

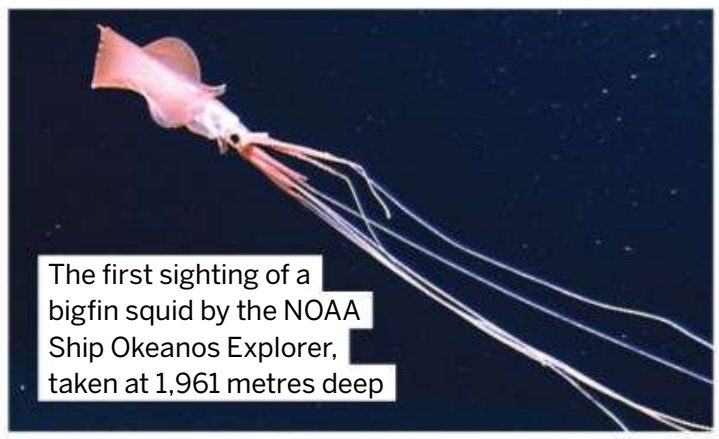
These transparent creatures get their name from the way they gracefully move through the water by flapping their wing-like structures. But sea angels aren't divine, instead belonging to a family of sea slugs, like their shelled cousin the sea butterfly (*Thecosomata*). Much like the comparison between garden slugs and land snails, these aquatic alternatives are free-swimming pteropoda, one of which is shelled, while the other is not.

Angelic as they may seem, these animals shouldn't be messed with. Using hook-like protrusions called buccal cones, sea angels suck out the bodies of sea snails and other shelled invertebrates and stuff them into their gut.

TWILIGHT ZONE

BIGFIN SQUID (*MAGNAPINNIDAE*)

Discovered in the last 20 years, the bigfin squid has been witnessed within the deep ocean around the world, but seeing one is rare. So far scientists have described three different species of bigfin squid, although there are likely to be more. The few sightings have found the squid bobbing a couple of thousand metres below the surface, and the deepest specimen was spotted almost 5,000 metres down. As their name suggests, bigfin squid are equipped with two large fins to propel them through the water, dragging around six metres of appendages along with them. These squid have eight arms and two tentacles, but it remains unclear exactly how these fascinating creatures use them.



The first sighting of a bigfin squid by the NOAA Ship Okeanos Explorer, taken at 1,961 metres deep

© Alamy / Getty / NOAA Ocean Exploration,Gulf of Mexico 2012 Expedition

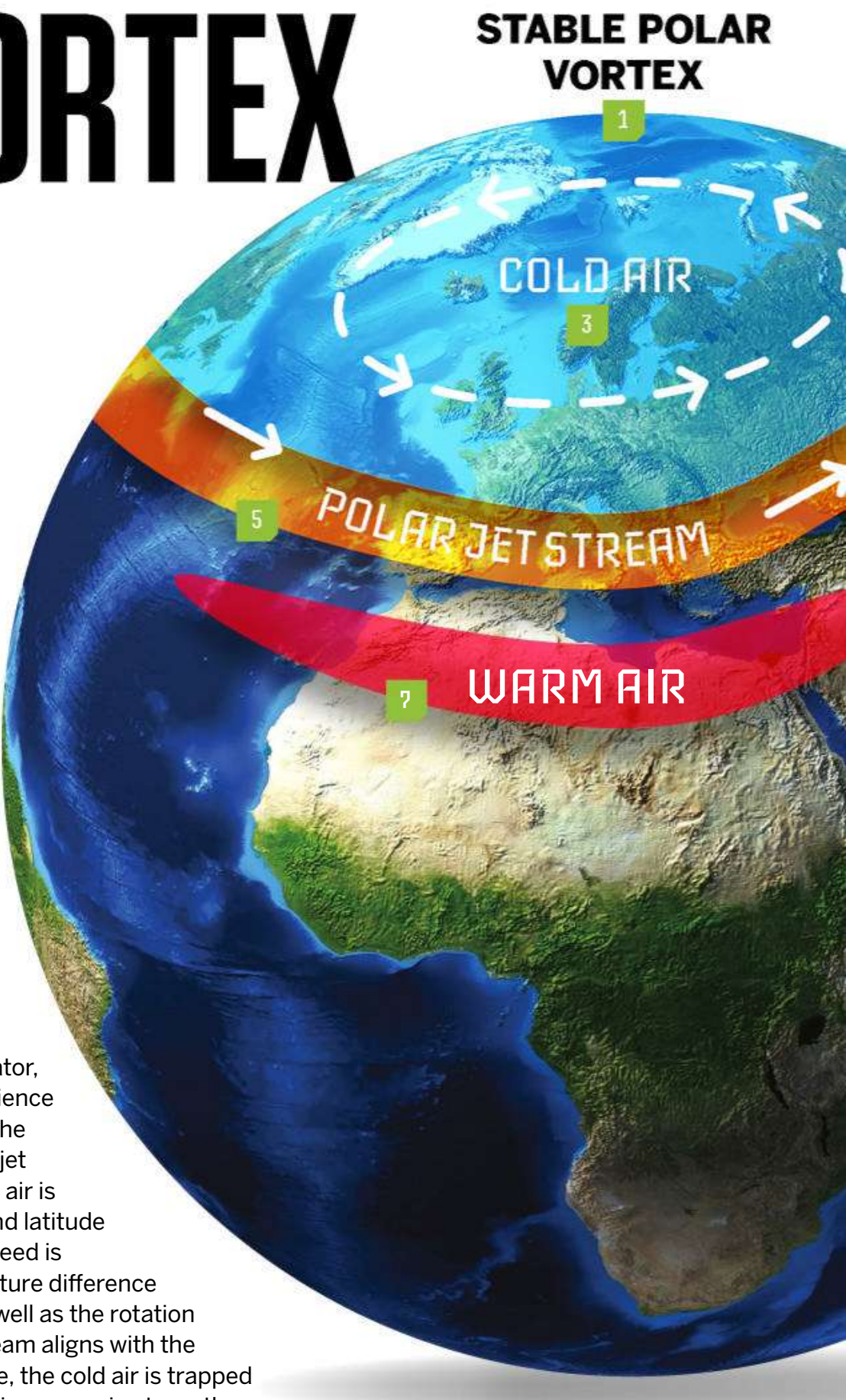
THE POLAR VORTEX EXPLAINED

What is the polar vortex, and how does it keep the climate in check?

WORDS **AILSA HARVEY**

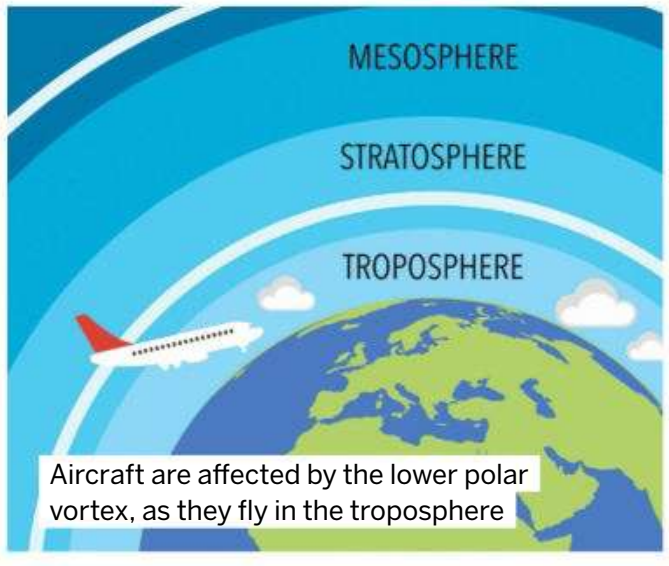
Did you know?

Planes use jet streams to travel faster



The Arctic has a reputation for frigid temperatures and dark, icy winters. These extreme conditions are disproportionately allocated to Earth's poles, but why is this? These cold traps are created by an incessant vortex of cold air that spins anti-clockwise around the planet in the atmosphere above the Antarctic and Arctic. These low-pressure bands of air are called the polar vortex.

Most of the time, the Arctic polar vortex stays near the pole. But its strength is always changing, causing its border to alter in shape and size. When it edges closer to the equator, the regions below it experience sudden gusts of wind. At the edge of a polar vortex is a jet stream. This circulation of air is usually lower in altitude and latitude than the vortex, and its speed is controlled by the temperature difference of the surrounding air, as well as the rotation of Earth. When the jet stream aligns with the vortex at the same latitude, the cold air is trapped at the pole and the vortex increases in strength.

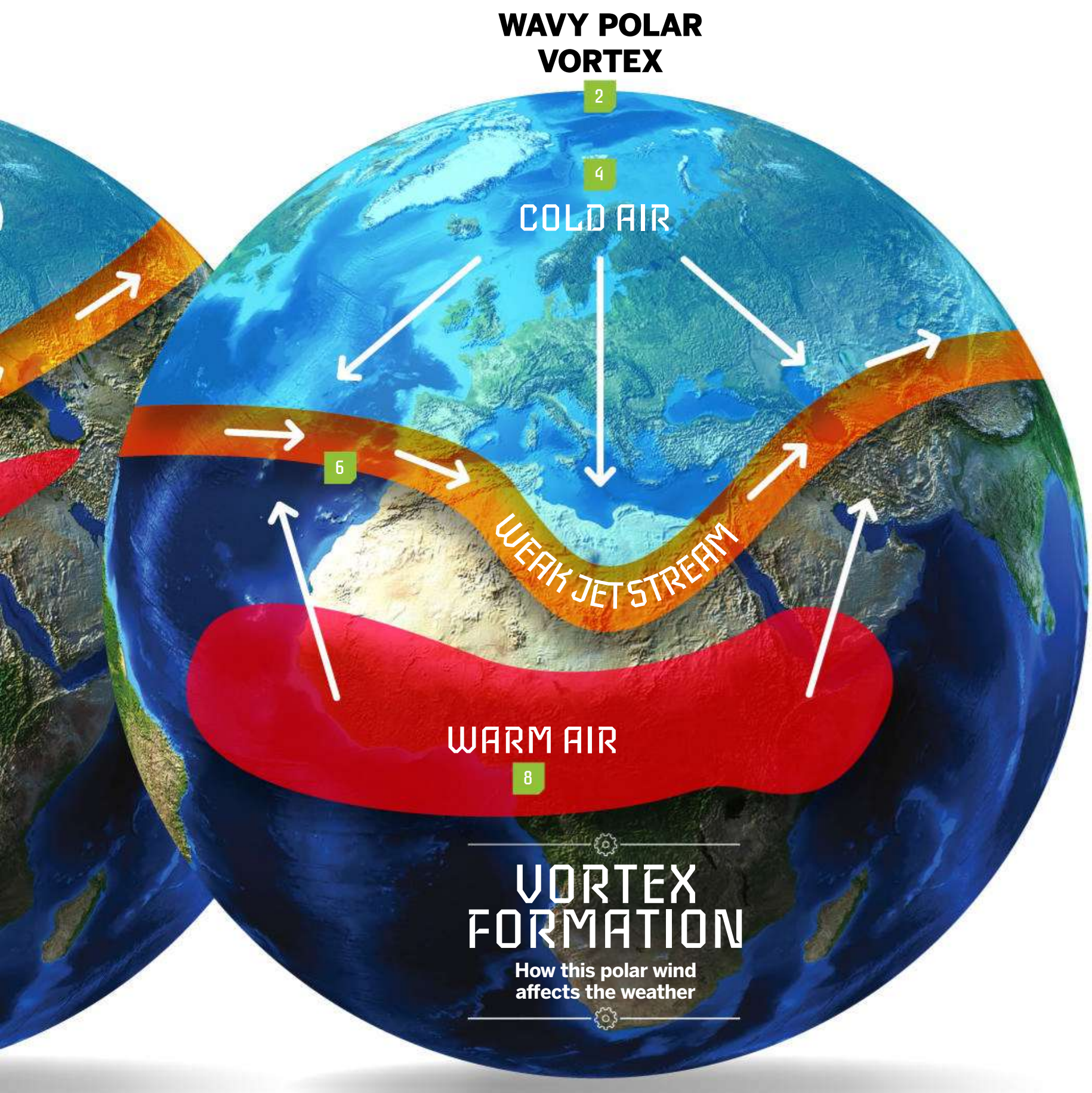


Aircraft are affected by the lower polar vortex, as they fly in the troposphere

DOUBLE TROUBLE

There are two polar vortices in each of Earth's hemispheres – one in the stratosphere and one in the troposphere. The troposphere is the lowest altitude layer of Earth's atmosphere, and the stratosphere is the second lowest. The vortex that's highest in the atmosphere is usually the more circular because it faces fewer obstacles. Meanwhile, the lower altitude vortex is more undulating, as there's mountainous terrain and more contrasting pressure systems to overcome. Being closer to Earth's surface, the tropospheric vortex has the greatest influence on the weather. In the Arctic, although this vortex is mostly constrained to the North Pole, when the jet stream is weakened it can drift further south. As this happens, it brings bitterly cold weather conditions. The stratospheric vortex isn't permanent. It usually disappears between March and September. When this vortex forms and holds a strong rotation, the coldest Arctic temperatures are less likely to venture southwards to more populous land.

DID YOU KNOW? In 2019, 21 people died from drastic weather changes after the polar vortex moved southwards



1 STABLE VORTEX
When the polar vortex is strong, the jet stream moves northwards, with wind travelling straight and smoothly.

2 WAVY VORTEX
If the polar vortex weakens, the jet stream isn't pulled northwards as tightly, making the wind's path more wavy.

3 COLD AIR
When fast-flowing air creates a tight band near the pole, the cold air is contained above it.

4 AIR DISPERSAL
A weak jet stream allows the cold air to move away from the pole and some warmer air to move towards it.

5 STRAIGHT JET STREAM
When the temperature difference across the jet stream is large, the jet stream is stable.

6 WEAK JET STREAM
During summer, the jet stream weakens and diverts further from the pole.

7 WARM AIR ZONE
The warm air is kept away from the polar vortex.

8 WARMING THE ARCTIC
When warm air is free to move towards the poles, it can cause ice to melt.

A weaker vortex reduces Arctic sea ice, as the warmer air causes it to melt

WARMING POLES

Global warming affects the entire planet, but the rate of warming varies at different latitudes. The Arctic's surface temperature, for example, is warming twice as quickly as Earth's surface average. This impacts the polar vortex because the stability of the vortex is maintained by the temperature difference on either side of the jet stream. If the pole increases in temperature much more than areas at lower latitudes, the temperature difference won't be as great. As a result, the polar vortex becomes weaker and more warm air can creep into the poles, warming them further.

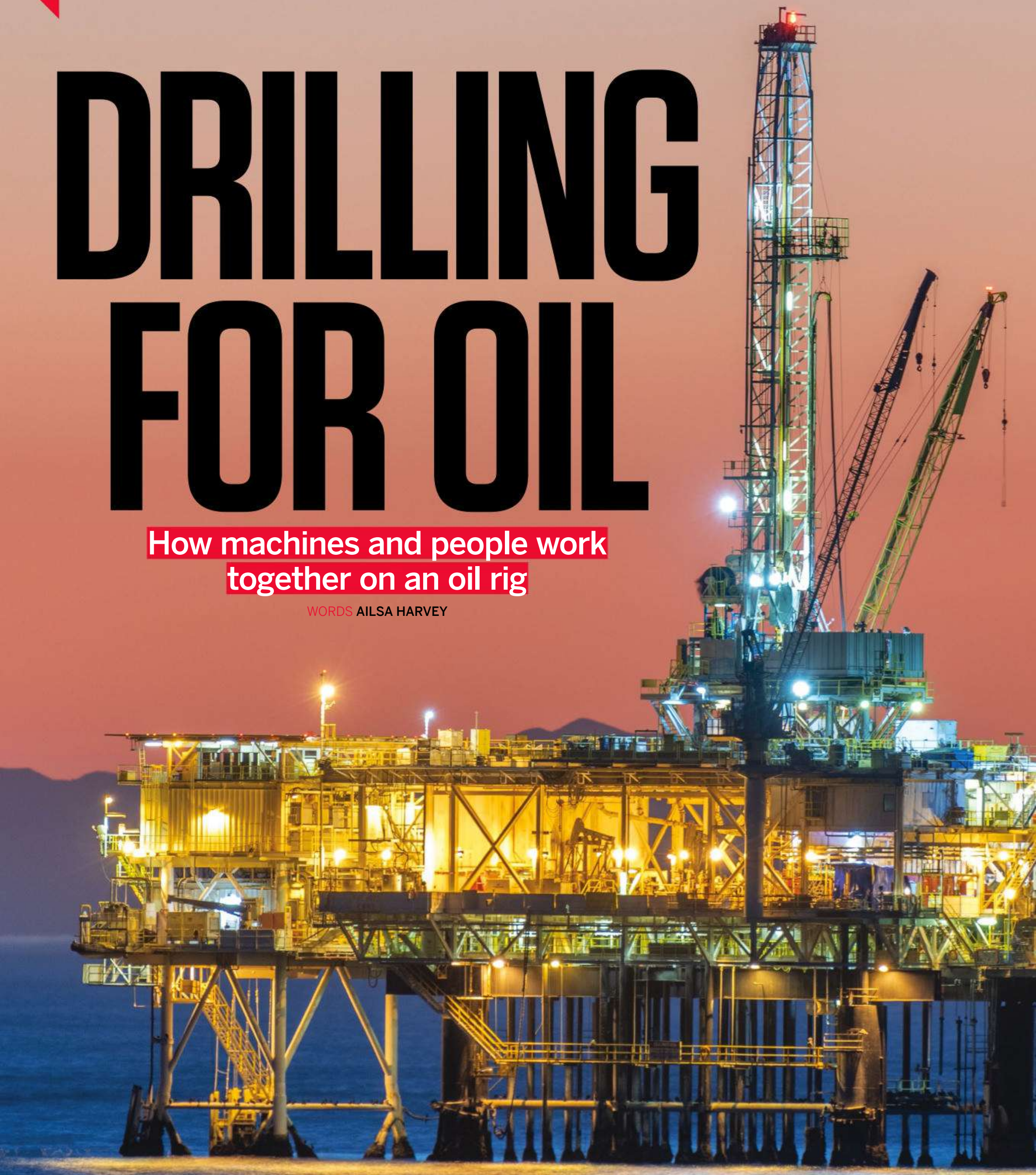
© Alamy / Getty

TECHNOLOGY

DRILLING FOR OIL

How machines and people work together on an oil rig

WORDS **AILSA HARVEY**



DID YOU KNOW? The world's deepest oil well is Z-44 Chayvo, which has drilled over 7.5 miles into the ground

Since the 1800s, large drilling platforms called rigs have been used to create holes in the ground. The purpose of these is to access and extract oil called petroleum, also known as crude oil, which can be used as an energy source for a range of purposes. For example, petroleum is converted into gasoline and diesel to fuel vehicles, heating oil to power boilers in home heating, jet fuel and propane for heating and cooking.

Oil is found underground in small pores between the rock. These oil-rich areas are called reservoirs and are the target area for oil rig activity. An oil rig is a large structure equipped with the facilities needed to drill into the ground and access oil reservoirs. These can be based both onshore and offshore. Onshore rigs are used to drill into Earth's surface, while offshore rigs drill into the seabed beneath the ocean.

Before an oil rig is built and begins drilling into our planet's surface, geologists need to analyse the ground to know how large a reservoir is, how many pores there are and how fast the oil will move between pores when a hole is drilled to release it. To work out the conditions of the rock and oil, scientists direct sound waves into the rock using special equipment called geophones. These devices record how fast the sound waves travel through the rock, and scientists analyse this data to find the best reservoirs.

When an oil rig's drill first enters an oil reservoir, breaking apart the rock that was concealing it, the oil begins to rise to the surface straight away. This is because the high pressure in the contained reservoir – due to the layers of rock pushing down from above – is released. The oil rig's drill, which is surrounded by a cylindrical metal casing, breaks into the rock. This casing serves as a tunnel through which oil can travel up towards the oil rig's main platform. When the drill has reached the reservoir, the drill is removed, keeping the casing in place. In order to make the installation more permanent, cement is poured into the casing, strengthening and securing the oil's route to the rig. A device called a blowout preventer is added at ground level to control the pressure being released from the reservoir and prevent dangerous explosions.

Did you know?

North America has the most oil rigs worldwide

WHO LIVES ON AN OIL RIG?

These roles keep offshore oil platforms running smoothly

PUMPER
Responsible for checking that oil pumps are operating well. This can involve changing the pumping speed so oil uptake matches delivery schedules.

MECHANIC
The oil rig mechanic repairs the platform's machines and vehicles. They will also carry out regular inspections.

CREW CHIEF
This person is in charge of the remaining team's shifts. The chief will allocate shift times to keep the rig running efficiently.

DRILL OPERATOR
Drill operators need to adjust the drilling pressure and position before stopping the process when enough oil has been obtained.

CHEF
At least one chef is needed on the oil rig at all times to make meals and snacks for the entire crew.

FLOORHAND
These crew members have a general role of setting up and taking down oil rig equipment. Strength is required to carry the heavy equipment.

MOTORPERSON
This person maintains the engine room and deals with any mechanical issues alongside the mechanic.

ENGINEERS
There are drilling, tooling and safety engineers, involving analysing the suitability of drilling sites, equipment and safety systems respectively.

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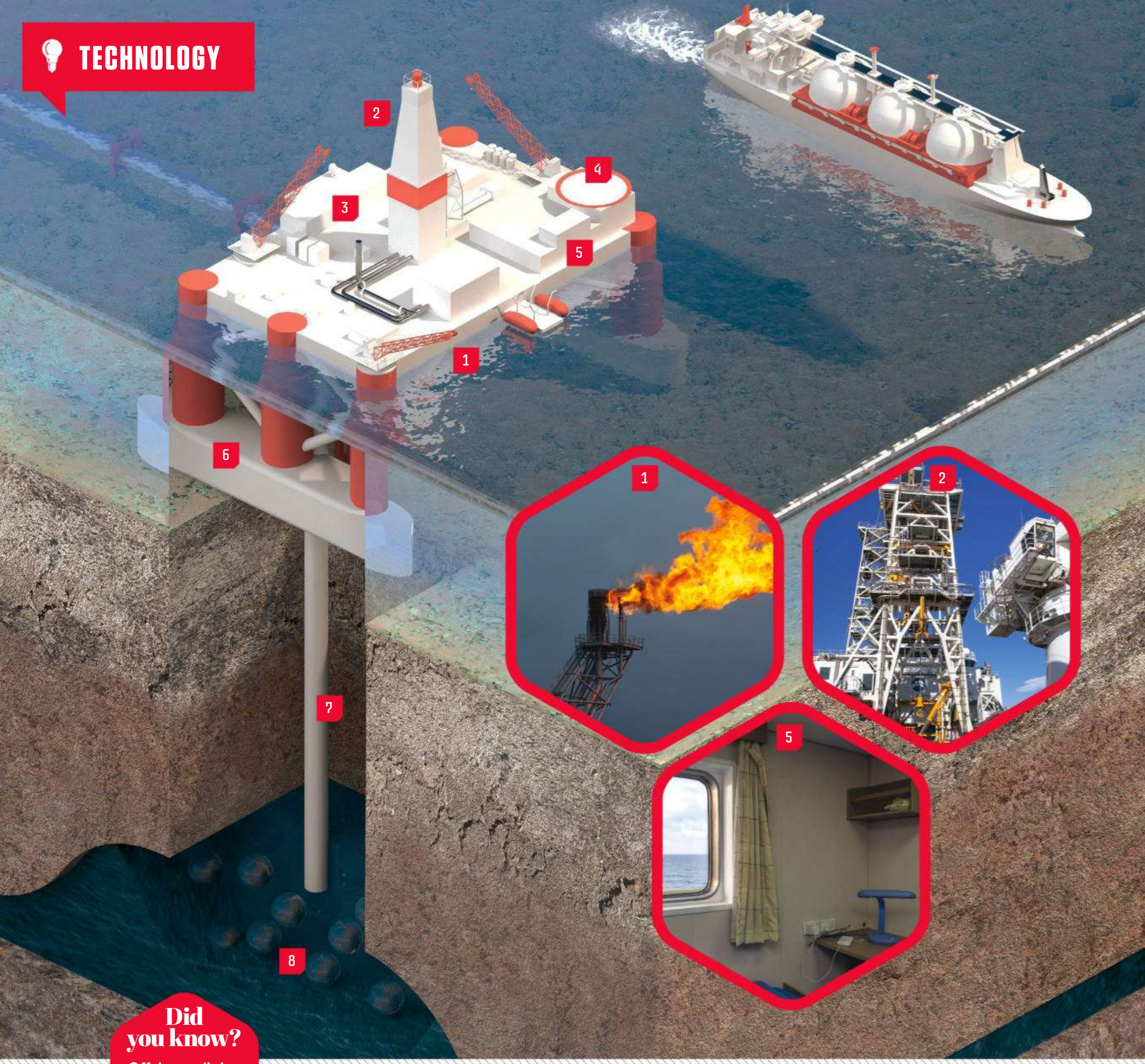


Did you know?

Offshore oil rigs are also known as 'floating cities'

OIL OPERATIONS

How does a platform's equipment pull oil from underground?

1 FLARE BOOM
Oil and gas are highly flammable, so any excess is drawn to the end of this crane where it can be burned safely away from the platform.

2 DRILLING MODULE
This module consists of a drilling machine and motor, which pushes the drill vertically into the seafloor.

3 DRILLING SUPPORT MODULE
The support module contains the materials needed for the drilling module to run. This includes a fuel tank, air compressor and electronics.

4 HELIDECK
Helicopter pads are installed on most oil rigs for crew members to travel to and from the rig. Helicopters are faster and more efficient than boats.

5 LIVING QUARTERS
With around 200 people living on oil rigs, crew members usually share a bedroom.

6 ANCHORS
Fixed oil rigs are attached to the seabed with substantial steel pillars.

7 DRILL PIPE
Oil is pumped from underground up to the surface through this hollow steel drill pipe.

8 UNDERGROUND RESERVOIRS
Oil lies in pockets beneath the ground called reservoirs. The built-up pressure is usually enough energy to push oil towards the surface.

DID YOU KNOW? In 2021, 89.9 million barrels of oil were extracted per day worldwide

SIX OFFSHORE RIG TYPES

1 FIXED PLATFORM
Conventional fixed platforms are attached to the seabed with steel pillars.

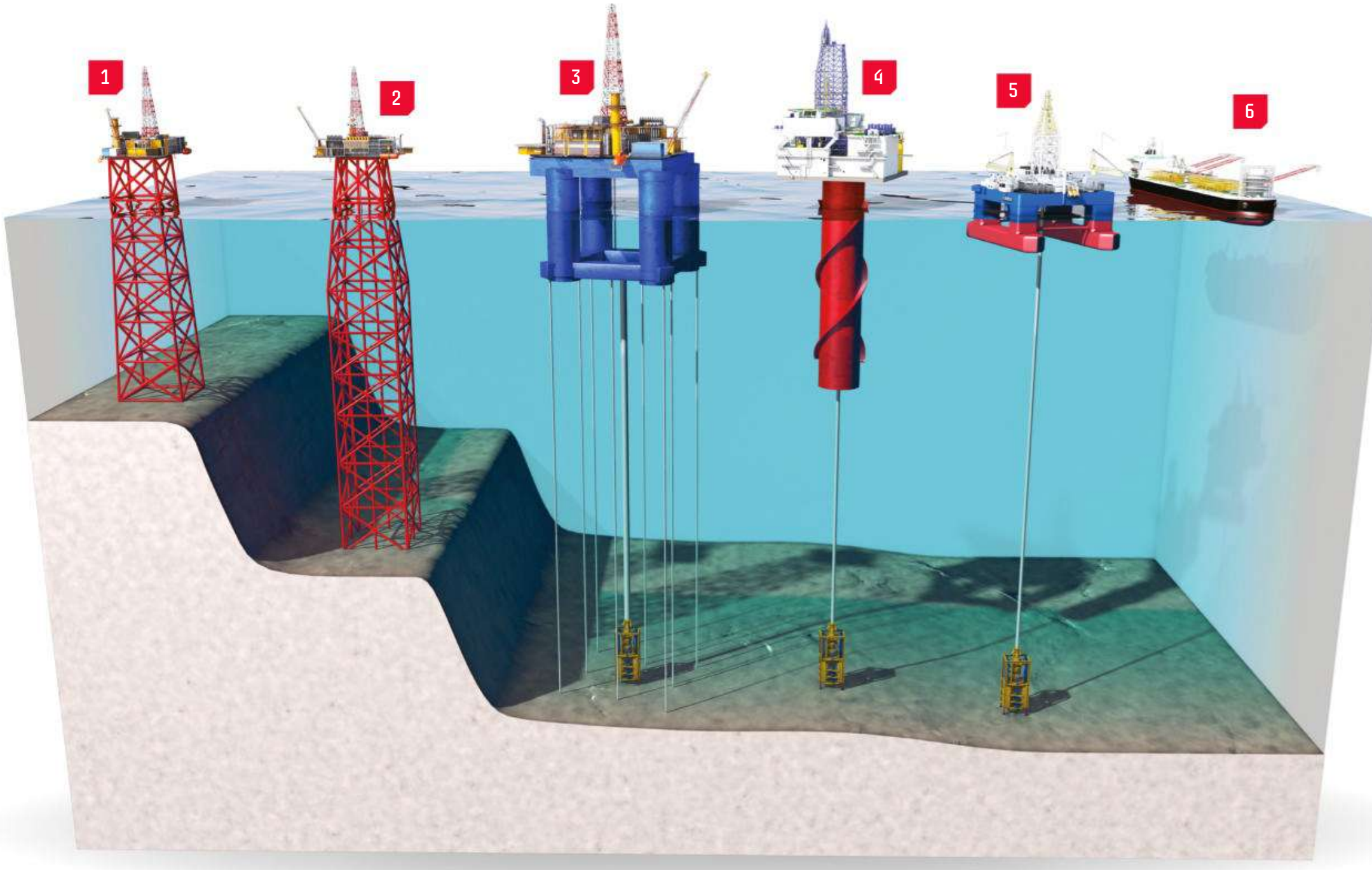
2 COMPLIANT TOWER
These towers are narrower than the fixed platform, making them more flexible and more likely to move with the environment.

3 TENSION-LEG PLATFORM
When the water is deeper than 300 metres, wires are used to attach a floating platform to the seabed. Because of the platform's buoyancy, the wires are stretched to keep the rig in a fixed position.

4 SPAR
Spar platforms have a vertical tension line as well as mooring lines that extend at a slight horizontal to further anchor the platform to the bed.

5 SEMI-SUBMERSIBLES
These platforms float above the waterline, but still have the majority of their mass underwater for stability.

6 FLOATING PRODUCTION SYSTEMS
These giant, floating vessels remain mostly above the water and are specially designed to store extracted oil.



WORLD'S LARGEST

Located just off Russia's eastern coastline, close to the island of Sakhalin, Berkut oil rig is the largest gas and oil platform in the world. In total the rig weighs around 200,000 tonnes and drills up to 35 metres into the seafloor. The platform area has a length of 105 metres, width of 61 metres and height of 145 metres.

Aside from its size, another impressive factor in this rig's operation is its ability to drill in harsh conditions. The area where it's built has extremely low temperatures and sees the formation of many floating icebergs. The oil rig is built with a strong concrete lining so that it's protected from ice caps up to two metres thick during the winter season. Additionally, the rig can tackle 19-metre-tall waves and high-magnitude earthquakes. In a single year, the Berkut oil rig can extract a maximum of 4.5 million tonnes of oil from the ground.

The Berkut oil rig is 15 miles from the island of Sakhalin's northern coast

© Alamy / Getty / Illustration by Adrian Mann

FITBIT SENSE TEARDOWN

How It Works explores the health-tracking technology of this smartwatch

WORDS **AILSA HARVEY**

Smartwatches are designed to be your daily health companion, and the Fitbit Sense is no exception. The watch is used to record exercise, track health data, show you the date and weather and help you keep track of the time. Working in the background of your everyday life, it continually updates your personal data, recording your breathing, skin temperature, blood oxygen level and heart rate. The Fitbit Sense can be treated like an extension of your smartphone, with multiple applications available to install. These include Spotify so you can quickly and easily control music without reaching for your phone, GPS applications to guide you on a journey while keeping your hands free and Alexa to control connected appliances simply by speaking into your wrist.

There's just one button, which is used to turn the screen on and off. However, in the settings you can change the display so that the screen automatically lights up when you lift your wrist. The entire watch face is touchscreen, making use of swiping and tapping to move and select items on the screen, just like a smartphone. One of the most popular uses of smartwatches is to record exercise sessions. Third-party applications such as Strava can track your route and time your exercise sessions, although the Fitbit Sense has a database of sports that it can track itself. Activity types include kickboxing, kayaking, pilates and skiing, as well as more mainstream sports. Specifying the activity type makes the record of calories burned and other data more accurate, and informs the watch computer of the type of movements your body is carrying out. The watch also has GPS technology, which works in the background to provide data like the distance travelled during sessions.

The appearance of the watch can be customised to suit the wearer's preferences. A selection of digital watch faces that you can change between are stored in its memory, while the straps can be physically removed and replaced. Each wearer will have their own use for the Fitbit Sense, but the multiple sensors within this device can help you understand different aspects of your body's health on a daily basis.

Did you know?

In 2021, there were 111 million Fitbit users

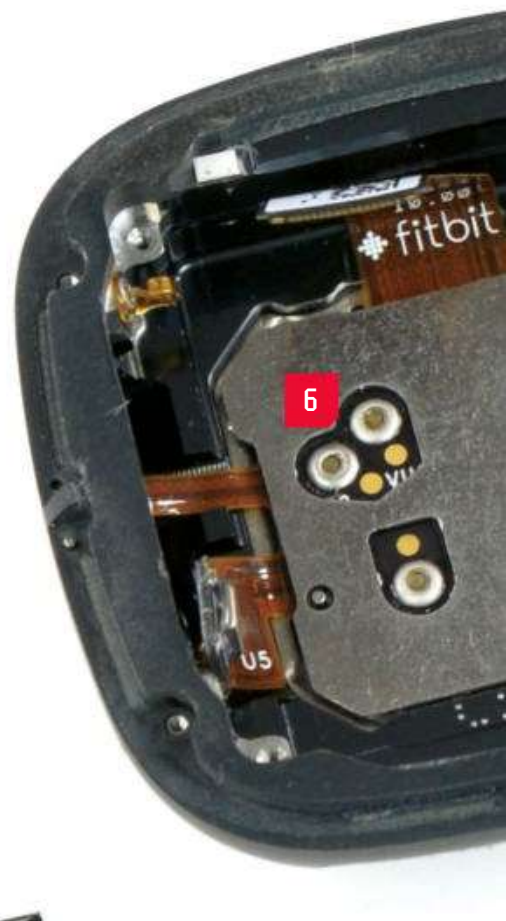
The Fitbit Sense's oximeter shows your blood oxygen level as a percentage

2

2 BATTERY
Once fully charged, the Fitbit Sense's battery can last up to 12 hours.

4

4 METAL BRACKETS
Two metal brackets border the watch's screen, detecting the wearer's heart rate and sweat levels on the skin.



6

6 O_2 SENSORS
Infrared lights flash onto the skin to estimate how much oxygen is in the blood. Blood with more oxygen absorbs more of the emitted light.

This shows the Fitbit Sense (middle) compared with the Fitbit Iconic (left) and Apple Watch Series 6 (right)

DID YOU KNOW? The Fitbit Sense is waterproof up to 50 metres

INSIDE FITBIT'S SMARTWATCH

It's teardown time

1 STORAGE
A four gigabyte flash memory module is housed on the motherboard.

7 VIBRATION MOTOR
When receiving notifications and alerts, the watch can be set to vibrate. This is the component that causes these vibrations.

3 SPEAKER SHIELD
When the watch is submerged in water, this protective component prevents water from infiltrating the speaker.

"The Fitbit Sense can be treated like an extension of your smartphone"

5 LOUDSPEAKER
A built-in speaker is located next to the microphone. These can be used to take phone calls when connected to a smartphone via Bluetooth.

8 RIBBON FLEX
This strip contains near-field communication (NFC) technology that enables Fitbit Pay: Contactless payments can be made using the watch in place of a connected bank card.

DETECTING STRESS

The body's physical symptoms can sometimes be indicators of a person's mental state. The Fitbit Sense not only tracks how active you are, but can monitor your stress levels. To achieve this, the watch is equipped with an electrodermal activity (EDA) sensor. This monitors electrical changes in the skin, which correlate to the sweat level in the wrist. When you get stressed, sweat is released in bursts from the skin. Those who wear this watch throughout the day will be able to track how many times the EDA sensor is triggered. The EDA data, combined with sleep data and resting heart rate, provides the wearer with a stress management score. After acknowledging stress patterns, the Fitbit Sense can guide you through mindfulness exercises to calm the brain.

The EDA scan can run while carrying out a mindfulness session or as a quick two-minute scan

© iFixit / Getty

WHAT IS THE CLOUD?

How the big computer network in the sky saves your photos, documents and more

WORDS **SCOTT DUTFIELD**

Taking inspiration from the fluffy, water-filled objects in the sky, the digital cloud has been designed to store every drop of data on your computer at the touch of a button. Every computer, smartphone or tablet comes with a limited memory to store a whole host of information, such as documents, images and music. Once the internal memory is full, you might employ a backup, such as a DVD, memory card or hard drive, to store more information. The cloud is just another method of storage; rather than plugging in another piece of hardware, all the information you want to store is sent and saved in servers around the world via the internet. Tech giants such as Amazon, Google and IBM operate hundreds of data centres and millions of servers around the globe that store consumer data that can be recalled through cloud services, such as Google Drive, Apple iCloud and Netflix.

What gives the cloud such a practical advantage over more traditional backup options is its accessibility. Without the cloud, your data is limited to the device it's stored on. However, the cloud allows users to save this data in a virtual space and access it from any device that's connected to the internet. This also means you don't have to clog up your device's internal storage. The main limitations of cloud storage are the need for an internet connection to access your data, the amount of server space available to you and the general security risk of sharing information through the internet. Outside of saving your family photos, favourite tunes and university essays, cloud computing has opened up processing power and other resources for many industries, including medical services, education, entertainment and gaming.

Did you know?

Amazon Web Services owns 32 per cent of the cloud market

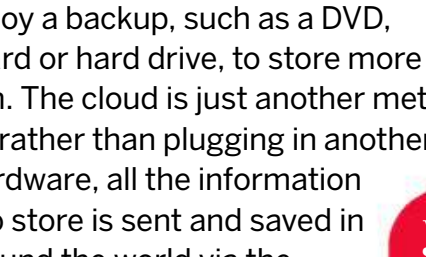
THE FIRST CLOUD

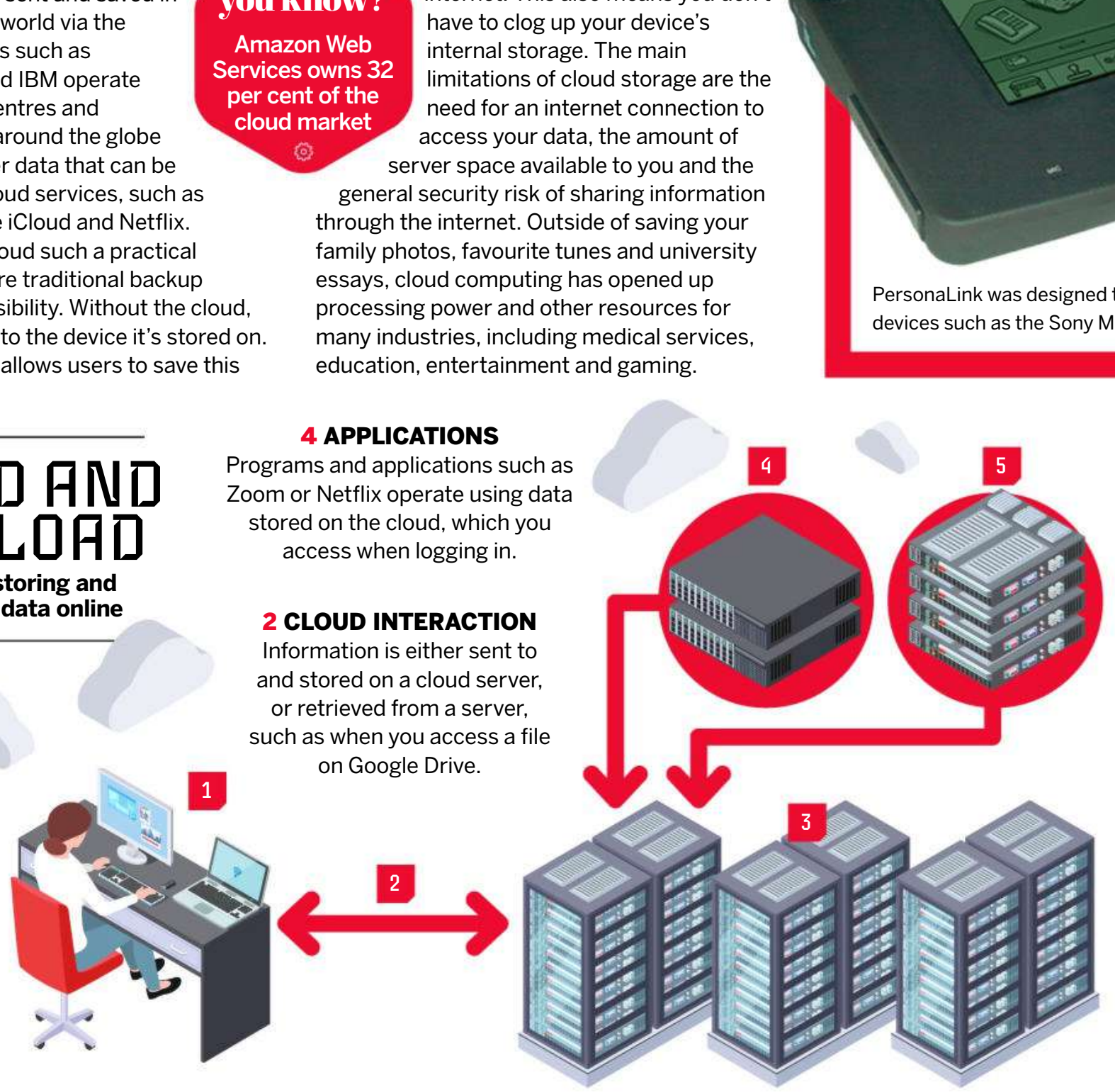
The first time that anyone used the word 'cloud' to describe data storage instead of a weather report occurred in 1994, when American telecommunications company AT&T launched a program called PersonaLink. The program used agents known as 'virtual assistants' to store and share information between personal computers via the internet. Information such as business reports, orders and contacts, along with the virtual assistants themselves, were stored in 'virtual storage area' servers. PersonaLink didn't take off in the way AT&T might have hoped, referencing the growth of the internet as a contributing factor to its demise. The program was axed in 1996.

PersonaLink was designed to run on devices such as the Sony Magic Link

UPLOAD AND DOWNLOAD

The basics to storing and retrieving your data online





1 DEVICE
Smart devices such as laptops, smartphones and tablets can connect to the cloud via an internet connection.

2 CLOUD INTERACTION
Information is either sent to and stored on a cloud server, or retrieved from a server, such as when you access a file on Google Drive.

3 SERVERS
Information is stored and accessed from millions of internet-connected servers around the world.

4 APPLICATIONS
Programs and applications such as Zoom or Netflix operate using data stored on the cloud, which you access when logging in.

5 DATABASE
The available storage space on the cloud is astronomical. It's estimated that by 2025 there will be 100 zettabytes of data on the cloud – one zettabyte is equal to a trillion gigabytes.

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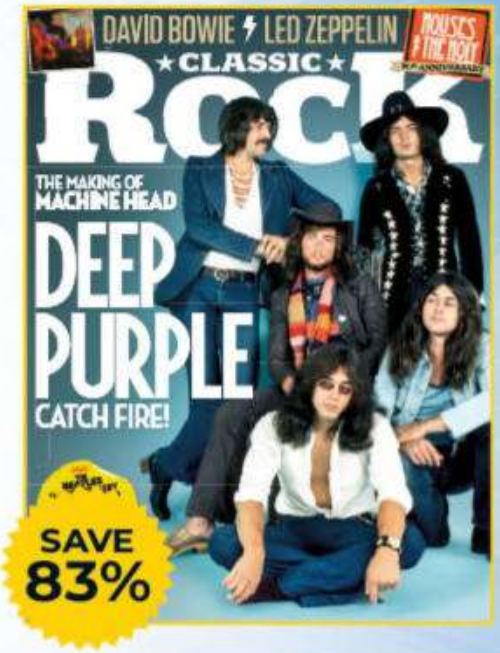

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INSIDE AIR FORCE ONE

What's on board the US president's personal aeroplane?

WORDS **AILSA HARVEY**

It's essential to track the whereabouts of any aircraft that takes to the sky. However, when one of the passengers on board is a high-profile government figure such as the President of the United States, the safety and security of the aircraft is taken much more seriously. Equipped with nuclear bomb-resistant materials and technology that can make it invisible to enemies, the president's aircraft is designed to be one of the safest aeroplanes on Earth. This plane is referred to as Air Force One.

Air Force One is not a term that refers to one specific plane, but any aircraft that is carrying the current US president. Even planes that are designed to carry the person at the top of the US government cannot be referred to as Air Force One until the president steps on board. The term was first coined in 1953 when the president's aircraft and a commercial airliner had the same flight number and entered the same airspace at the same time. To prevent air-traffic controllers

Former president Barack Obama speaks with advisors aboard Air Force One

from confusing the president's plane with another aircraft, Air Force One has been used as its designation ever since.

The two current Air Force Ones are Boeing 747-200Bs. These models have been in service as the presidents' jets since 1990, so to stop them becoming too outdated, a new generation of Air Force Ones are under construction. The new model will be the Boeing 747-8. To keep the aircraft secure, many of the details are classified, but its features are expected to remain similar to the current Air Force One planes – providing a high level of luxury and safety on all of the president's future trips.

This presidential Douglas VC-54C was better known as the 'Sacred Cow'

THE FIRST PRESIDENTIAL PLANE

In 1910, Theodore Roosevelt became the first US president to travel by plane. But the first to ride in a plane designated for their own personal use was Franklin D. Roosevelt. Since then, each new president has flown in a specific Air Force One plane to make air travel safer for them than travelling in a commercial aircraft. The first presidential plane, built in 1945, was officially called the Flying White House and was a Douglas VC-54C aircraft. It was more commonly known by its nickname the 'Sacred Cow'. This was used to fly the president to the Yalta Conference in February 1945, but the identity of the plane was concealed by changing the flight's serial number. This is because the Yalta Conference was a post-World War II meeting alongside other government leaders. Just two months later, Roosevelt died, making this the only flight he took in the first Air Force One. However, the same aircraft was used for all of Harry S. Truman's flights for over two years. The Sacred Cow was where the US Air Force was established when, in 1947, Truman signed the National Security Act on board the plane. This made the Air Force an independent service and continued its use in maintaining presidential safety.

President Joe Biden is pictured exiting the Air Force One aircraft

Did you know?

Air Force One has enough food on board to last three days

© Alamy

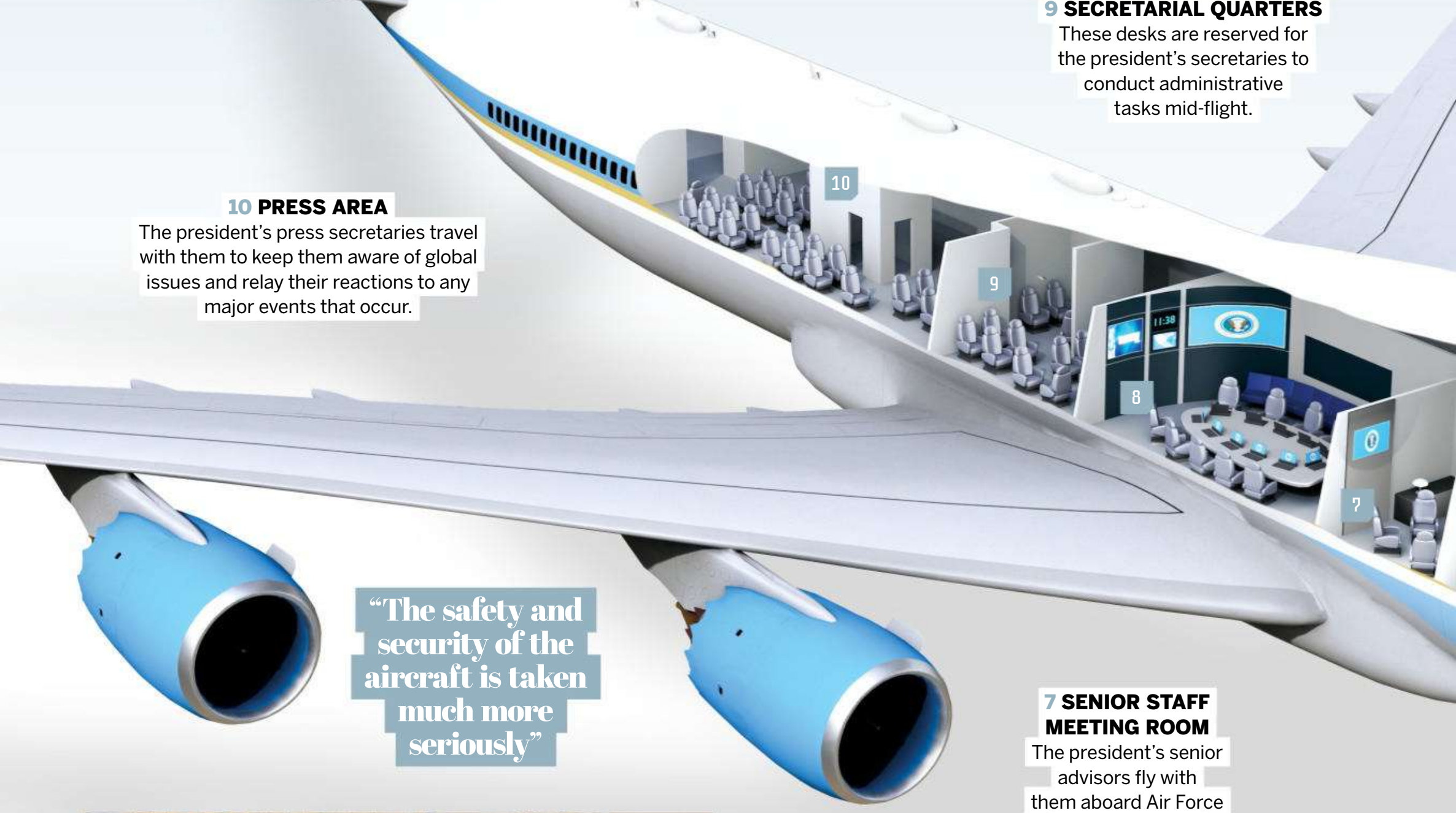
INSIDE THE AIRCRAFT

Explore the facilities on board the US president's new high-security plane

Former president Donald Trump holds a mid-air emergency meeting following a hurricane

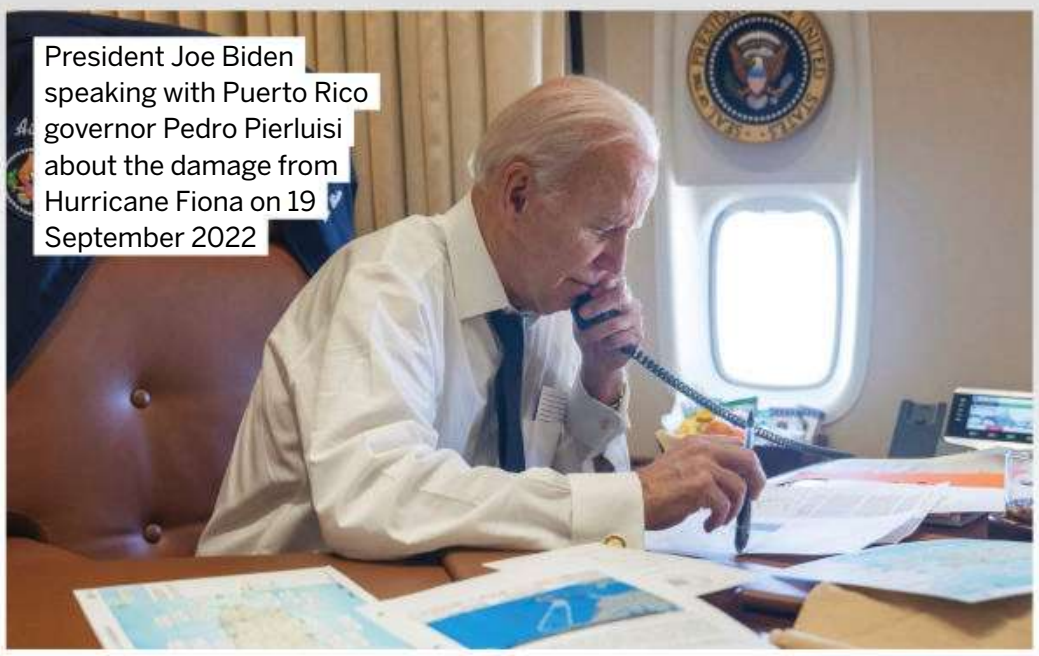
9 SECRETARIAL QUARTERS
These desks are reserved for the president's secretaries to conduct administrative tasks mid-flight.

10 PRESS AREA
The president's press secretaries travel with them to keep them aware of global issues and relay their reactions to any major events that occur.



> "The safety and security of the aircraft is taken much more seriously"

7 SENIOR STAFF MEETING ROOM
The president's senior advisors fly with them aboard Air Force One. Top-secret meetings can be conducted in this room.



President Joe Biden speaking with Puerto Rico governor Pedro Pierluisi about the damage from Hurricane Fiona on 19 September 2022

8 PLANE DINING
Air Force One's kitchen is always open and can make up to 2,000 meals per flight. The food is tested before being consumed by the president.

DID YOU KNOW? There are two Air Force One planes, ensuring there's one ready to fly at all times

400 SQUARE METRES

The plane has a floor space the area of one-and-a-half tennis courts

$3.9 BILLION

The cost of the two new Air Force One aircraft equals that of nine standard Boeing 747-8s

374,850KG

The maximum takeoff weight for the current Air Force One

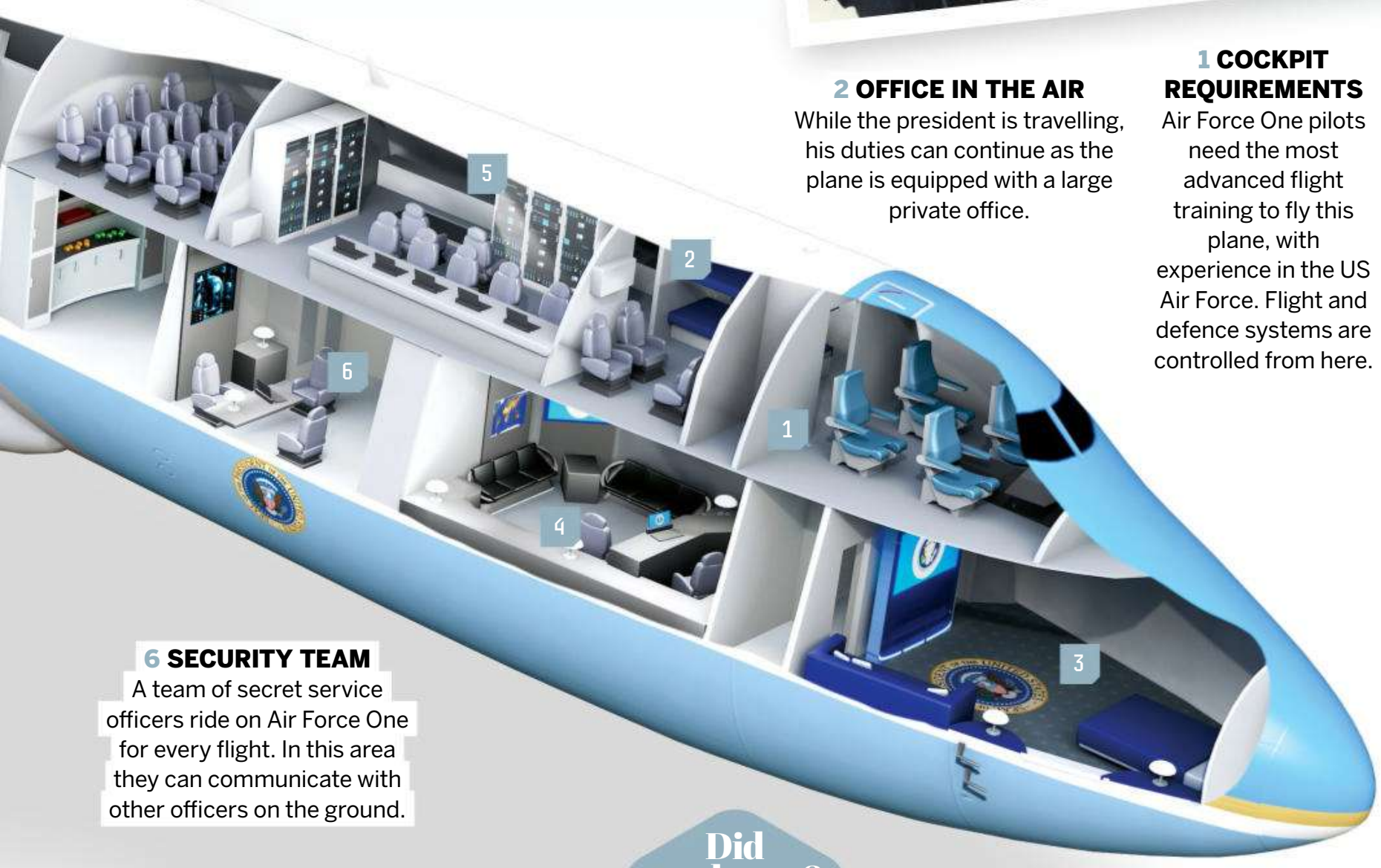
70

It can carry a substantial crew

600MPH

Air Force One can travel close to the speed of sound

Former president Ronald Reagan plays mini golf on route to the Geneva Summit in 1985



5 COMMUNICATIONS ROOM

This area is shielded from electromagnetic interference. There are multiple televisions and 85 telephones, keeping the presidential team in touch with events on the ground.

2 OFFICE IN THE AIR

While the president is travelling, his duties can continue as the plane is equipped with a large private office.

1 COCKPIT REQUIREMENTS

Air Force One pilots need the most advanced flight training to fly this plane, with experience in the US Air Force. Flight and defence systems are controlled from here.

6 SECURITY TEAM

A team of secret service officers ride on Air Force One for every flight. In this area they can communicate with other officers on the ground.

4 MEDICAL SUITE

There's always a doctor on board Air Force One, with a designated area equipped with emergency supplies.

Did you know?

There's an operating room on board Air Force One

3 PRESIDENTIAL SUITE

This is a place for the president to relax while travelling. Included are a bed, sofa, television screens and a personal gym and bathroom.

5 AF1 SAFETY FEATURES

1 ANTI-MISSILE
The plane can intercept missiles from the ground and air by releasing infrared light to disrupt their sensors. By ejecting flares, missiles can no longer accurately detect the heat from the plane's engines.

2 ANTI-RADAR
The plane is equipped with technology to block any enemy radar. This involves emitting radio signals that interfere with radio waves from other aircraft, to prevent them returning to the receiver with location data.

3 IN-AIR REFUELLING
Previous Air Force One models can be refilled with fuel mid-air. This can keep the aircraft in the air for longer. As this feature hasn't been utilised in the past, the newest Air Force One could lose this technology.

4 BLAST-PROOF
The aircraft is substantially shielded to protect it from the dangerous radiation released in a nuclear explosion.

5 RADIATION BLOCKING
The plane's windows are covered in a wire mesh that protects the aircraft from a damaging electromagnetic pulse.

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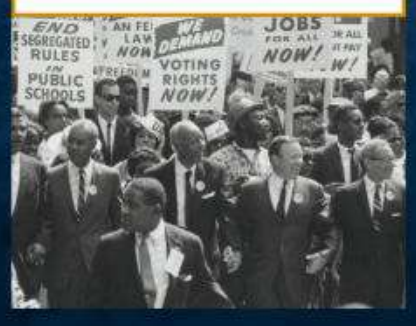				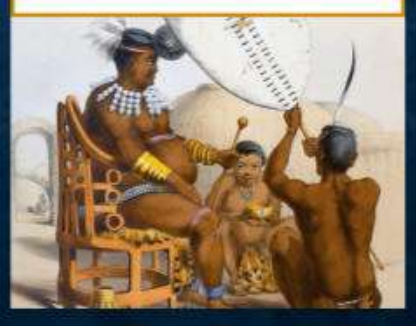

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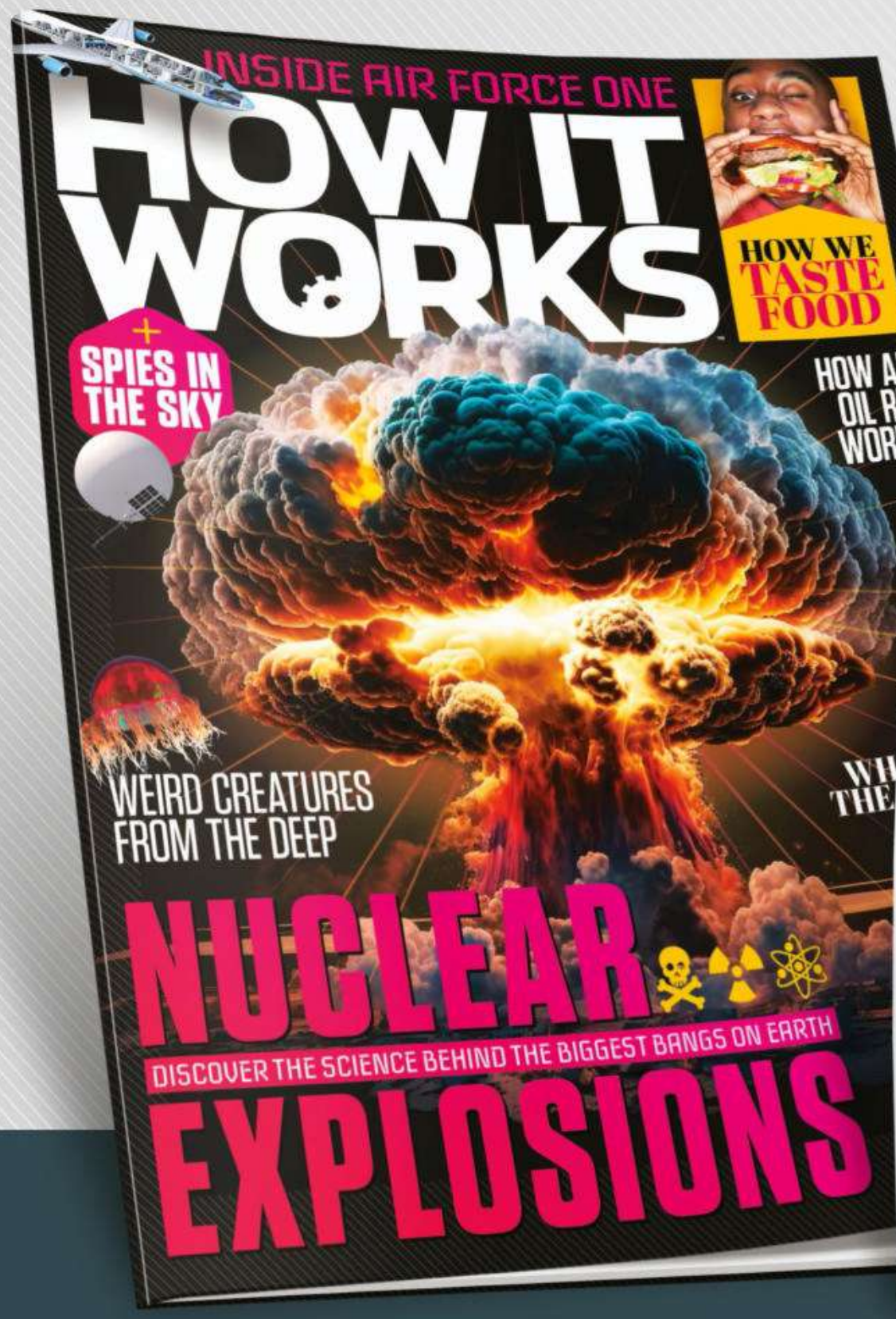
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BRAINDUMP

Amazing answers to your curious questions

What was the largest herbivore in the time of the dinosaurs?

William Borde

The largest dinosaur herbivore – and the largest herbivore of all time – was a sauropod named *Argentinosaurus*. As the name suggests, its remains have been found only in Argentina. No complete skeleton has ever been discovered, but individual backbones from *Argentinosaurus* are over 1.5 metres tall – taller than many adult humans. It has been estimated that a fully grown *Argentinosaurus* would have weighed over 70 tonnes, more than ten fully grown African elephants. Several ideas have been proposed to suggest why sauropods got so large, including the need for very large digestive systems to deal with tough, fibrous plant food.

WHICH METAL HAS THE HIGHEST MELTING POINT?

Lei Smith

Tungsten, often referred to as wolfram in other parts of the world, has the highest melting point of any metal. Extracted from wolframite, scheelite and other minerals, it is a grey-white metallic element and is incredibly dense and extremely hard. In fact, it is the second-hardest material – only beaten by diamond – has a greater density than lead and does not break down or decompose, meaning it's also environmentally friendly. This range of properties means that tungsten is used in many industries and products, from high-speed cutting tools and jet turbine engines to shotgun ammunition and fishing weights.

Did you know?
Tungsten melts at 3,422 degrees Celsius

WHAT IS BRITAIN'S LARGEST LIZARD?

John Kay

Britain is home to three native species of lizard: common lizards (Zootoca vivipara), sand lizards (*Lacerta agilis*) and slow worms (*Anguis fragilis*). The longest is the slow worm, which can reach up to 50 centimetres in length – it's sometimes mistaken for a snake, as it has no legs. They are distributed across Britain and are often found in gardens, particularly in compost heaps or under logs. Despite being widespread, they are protected by law.

HOW DO DIGITAL CAMERAS CAPTURE IMAGES WITHOUT USING FILM?

Lucy Ripley

Instead of film, digital cameras use an electronic detector to register light. There are different types of sensors, but the main thing is that when light particles (photons) hit it, electrons get out, creating an electric signal. The sensor is divided into tiny areas called pixels. These are the small dots or squares you can see in the picture. On most cameras, different pixels receive light for red, green or blue. A basic computer built into the camera converts the signals from the pixels into an image that can be understood by a computer.

Why does the buzzing of wasps and bees differ?

Sheila Moss

The pitch of the buzzing noise made by bees and wasps depends on the number of wing beats per second. The smaller the bee or wasp, the higher the number of beats, resulting in a high-pitch sound. The larger the bee or wasp, the lower the number of wing beats, resulting in a low pitch sound. Another factor is the age of the insects; older ones will have some damage to the surface and edges of their wings. This lowers the number of beats per second, altering the sound pitch.

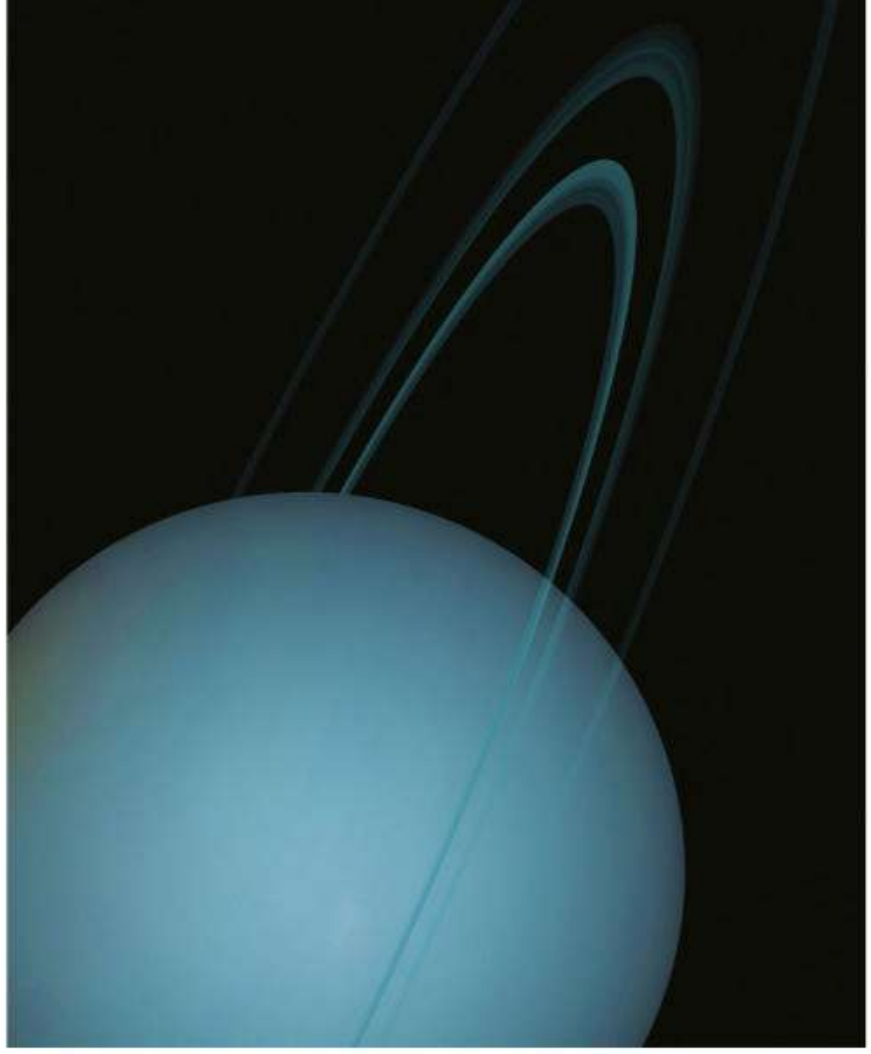
© Getty

BRAINDUMP

WHAT ARE URANUS' RINGS MADE OUT OF?

Louis Aston

The majority of Uranus' rings are opaque, and only a few miles wide. We now know that Uranus has at least 13 distinct rings. They are considered to be quite young, meaning they didn't form with the planet. The matter in the rings may once have been part of a moon or moons that were shattered due to high-speed impacts. The different rings vary in composition, but in general are made of a mixture of large bodies of water ice and an unidentified dark material. The nature of this material is unknown, but it may be organic compounds that have been darkened by irradiation. They contain relatively little dust.



I've heard you can eat nettles. Are there any that aren't safe?

Pranav Kumar

You can eat any nettle in the UK. Look for fresh, young plants. Pick them with rubber gloves and strip the leaves off the stem. There are many ways to cook them – steamed like spinach, fried with butter or in a stew. If you grip a nettle firmly, it shouldn't sting you. The stinging nettle is poisonous, but only on contact with the skin. It's the little hairs on the leaf that sting you. The hairs snap, and formic acid injects into you. Some tropical nettles have a sting that's so powerful it has been known to kill a horse.

WHO DESIGNED LONDON'S CLASSIC RED DOUBLE-DECKER BUS?

Kevin Drake

The famous Routemaster bus was developed by London Transport working with AEC and Park Royal Vehicles. It went into service in 1956. Bill Durrant, Eric Ottaway and a team of engineers produced a standardised design that could be easily maintained. The design was based on engineering principles developed during wartime aircraft production. The lightweight aluminium body had no separate chassis and fully interchangeable parts for easy maintenance. Other features included independent front suspension, coil springs, power hydraulic brakes, an automatic gearbox and power-assisted steering.

WILL THE APES OF TODAY CONTINUE TO EVOLVE INTO A NEANDERTHAL-LIKE SPECIES?

@dale_isard

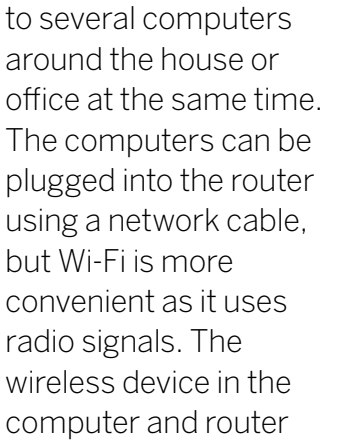
Not necessarily, as organisms can evolve in differing directions from the tiniest of initial variations. *Homo sapiens* are but one descendant of a common ancestor that lived 6 million years ago. From that common ancestor, various evolutionary paths emerged. Driven by multiple factors – such as climate change – this created multiple new species. It's a common misconception that evolution is a linear, isolated process. Just because *Homo sapiens* evolved from an extinct species of ape, it doesn't mean all apes will evolve into early humans. This is partly due to the inability to predict future conditions on Earth, but also because natural selection doesn't always lead to a generation of more complex organisms. On the contrary, natural selection in many cases tends to lead to simplicity, with organisms losing abilities and features that do not benefit their chances of survival. A good example of this is cavefish – due to their natural environment being deep waters within caves, swamps and lakes where there is little or zero light, they've lost their eyes completely.

What is the biggest species of tree in the world and is it true that you can measure a tree's age by its number of rings?

Claire Saul

It depends on what you mean by biggest. The tallest tree is a coast redwood (*Sequoia sempervirens*) at 115 metres tall, but that with the largest volume is the giant sequoia (*Sequoiadendron giganteum*), which has a more substantial trunk. The Californian tree known as General Sherman contains an estimated 1,486 cubic metres of timber. But the stoutest single trunk belongs to the baobab (*Adansonia digitata*), the biggest of which had a diameter of 15.9 metres. Some trees such as the European aspen (*populus tremula*) produce suckers so that a whole forest might be just one individual. You can age some trees by their rings, but only trees which grow in seasonal climates produce them, and even then decay of the heartwood in the centre means finding an age isn't always possible. The great basin bristlecone pine (*Pinus longaeva*) is the oldest verified by tree ring counts, at 4,844 years.

Did you know?
The Fortingall Yew in Perthshire is the UK's oldest tree



HOW DOES WI-FI WORK?

Jacob Brett

Most people use a router to connect to the internet. This gadget sends and receives information from a phone line or TV cable and can handle this information, connecting to several computers around the house or office at the same time. The computers can be plugged into the router using a network cable, but Wi-Fi is more convenient as it uses radio signals. The wireless device in the computer and router then work like two-way radios, sharing large amounts of information. The router can use different radio channels, but the information packets are addressed to a specific machine. To ensure that these communications stay safe, there are different ways to encrypt it, and that's why you need to set up a password.

© Alamy / Getty

Is it true that licking frogs can cause hallucinations?

Ralf Peterson

Many amphibians have properties within their skin secretions that can affect the human body. With hallucinogenic properties, toads are one of the main culprits. Toads in the genus *Bufo* usually have enlarged paratoid glands on their body which secrete toxins. For some species this toxin contains a chemical called bufotenine, which is known to be a hallucinogen. Licking some species may cause hallucinations, although as other toxins are also ingested along with the bufotenine the effect varies, and may just make the licker very sick.

Did you know?
The golden poison frog is highly toxic

WHY WAS THE 'IDA' FOSSIL FIND SO CONTROVERSIAL?

Gavin Mann

Ida (*Darwinius masillae*) was so controversial upon its unveiling as it was hailed by members of the discovery team as a potential 'missing link' between primitive primates and anthropoids – the group of which apes, monkeys and humans are members. This created a stir in the scientific community and was widely reported by international media. However, most scientists today class *D. masillae* as an adapiform primate. Adapiforms are one of the earliest known groups of fossil primates and are part of a suborder that includes lemurs, which are only distantly related to humans.

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WERE ALL THOSE FOUND GUILTY AT SALEM BURNT AT THE STAKE?

Frazer Mcleod

The Salem witch trials of 1692 are remembered as one of the most famous examples of the dangers of mass hysteria, isolationism, religious extremism and lapses in due judicial process. The trials consisted of a series of hearings to prosecute a number of people for the crime of witchcraft, which at the time was considered a real and present threat. The most famous of these trials occurred in Salem, where 26 people were brought to court, convicted and killed. Due to the wealth of misinformation and hearsay that followed, a myth surfaced that the convicted were executed by being burnt at the stake. In fact, the reality was far more mundane and cruel.

Over the four sessions of the trials, 29 people were found guilty of witchcraft. Of these, 19 were executed by hanging, 8 died in prison from injury and neglect and one man, named Giles Corey in historical records, was crushed to death under heavy stones. To date, there's no recorded evidence that any of the convicted persons were burnt. A memorial park lies in Salem with a stone bench dedicated to each of those killed.

WHAT ROLE DID THE ROMAN CATHOLIC CHURCH PLAY IN THE BATTLE OF HASTINGS?

Simon Schweir

Whereas in Normandy the Church was experiencing growth, expansion and reform, in England monastic and ecclesiastical life was in decline. There was also the issue of married clergy – a problem that reforming popes were keen to tackle throughout Europe. The pope of the time, Alexander II, sent a papal banner to Duke William of Normandy to show his support for his invasion. During the reign of Edward the Confessor, the archbishop of Canterbury had been dismissed from office. A new claimant, Stigand, made archbishop. However, his appointment was uncanonical – it did not conform to Church law. William promised to rid England of Stigand in return for papal support of his invasion. Following the conquest, William established Lanfranc, a monk from the monastery of Bec, near Rouen, as archbishop of Canterbury. William and Lanfranc sought major Church reforms.

WHY ARE SUNFLOWER HEADS SO LARGE?

Jennifer Tanner

The most likely reason is that sunflowers follow the Sun during the flowering season – a process called phototropism. Can large flower heads sense the light easier and absorb more sunlight? Maybe. Perhaps sunflowers are so productive because they stay in close contact with their source of nourishment, never turning their back on the Sun – the source that provides the energy to be changed into so many useful products. There are giant sunflowers that grow huge flowers, and other varieties of sunflower that don't. One reason they are so large is that it's part of their genetic makeup. Sunflower heads look like one flower, but they are actually made from two parts: the yellow 'petals', which are a kind of leaf that protects the flower while it grows, and the brown centre, which is a bunch of tiny flowers called florets, consisting of petals, stamens and anthers.

Why do howler monkeys make such a racket?

Abigail Staines

Howler monkeys, which are considered the loudest land animal, can produce such a loud call as they have an enlarged hyoid bone in their neck. This bone, which usually resembles a horseshoe and aids tongue movement and swallowing, has developed into a large shell-like bone in the throat that grants extra engorged resonance to any produced noise. The reason howlers utilise this bone so frequently to create loud howls, however, is that it is through this form of communication that territorial boundaries are established, with rival clans marking their territory each day at dawn and dusk.

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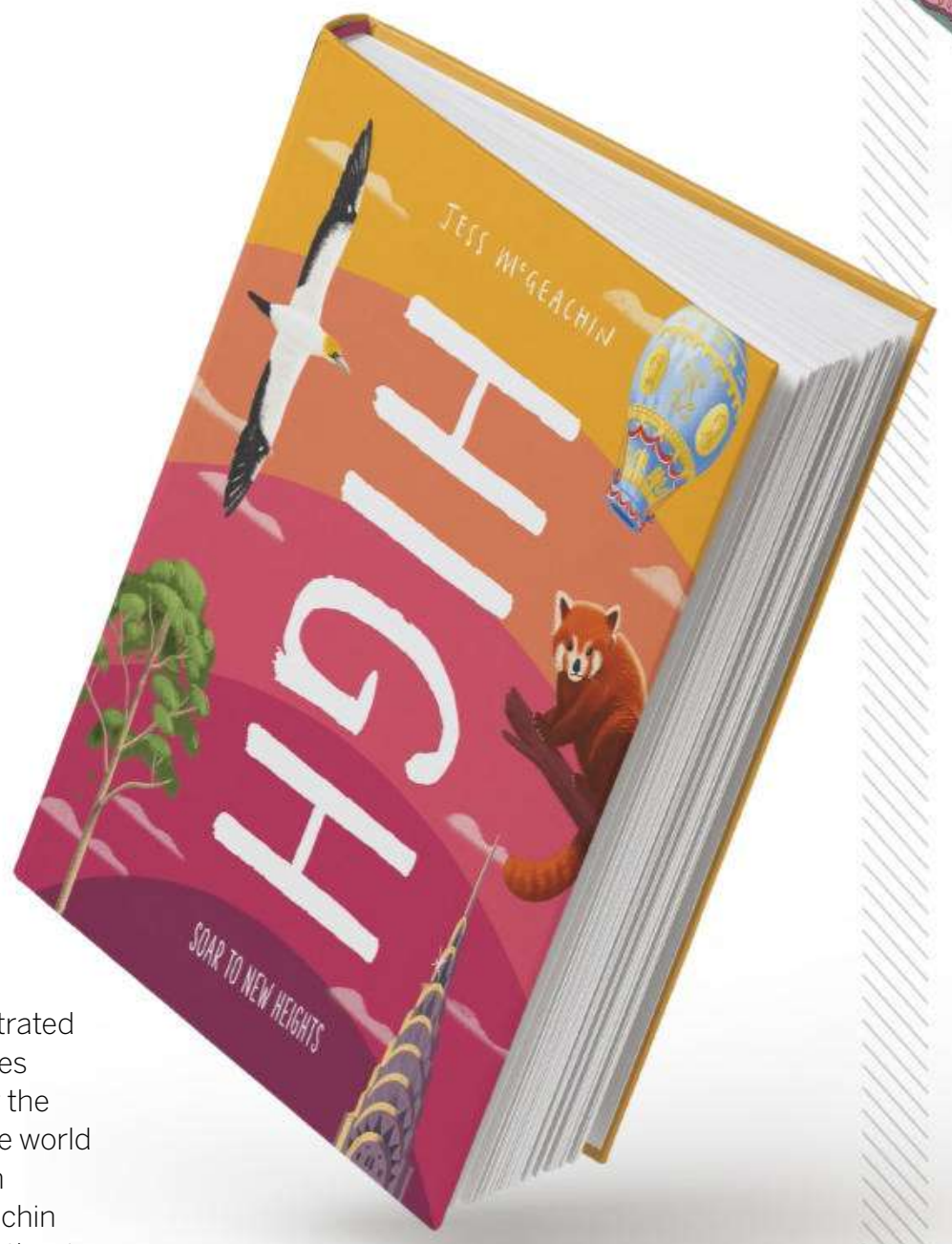
The latest book releases for curious minds



HIGH

EXPLORE THE WORLD FAR ABOVE OUR HEADS

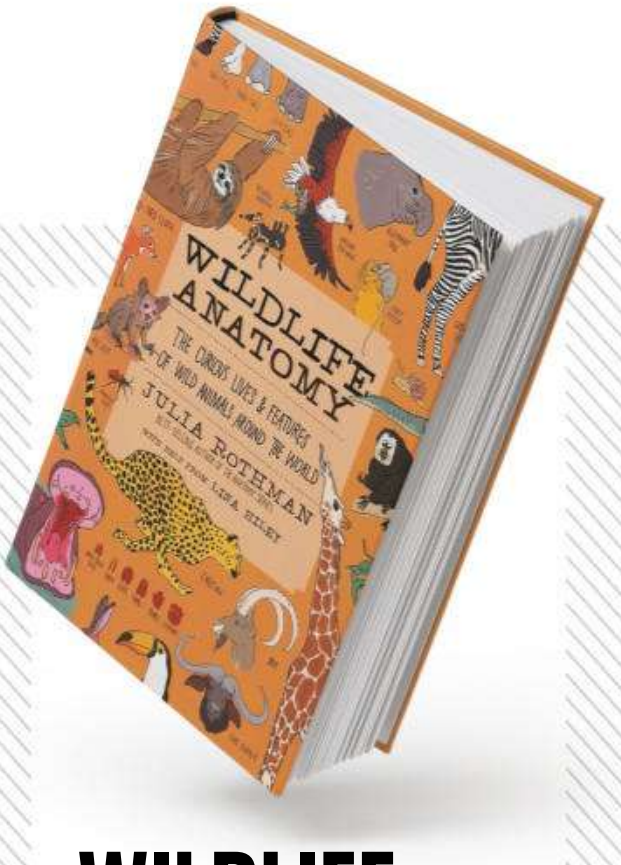
AUTHOR **JESS MCGEACHIN**
PUBLISHER **WELBECK EDITIONS**
PRICE **£14.99 / $16.95**
RELEASE **OUT NOW**

High is part of a series of illustrated children's books that includes *Lost* and *Deep*, respectively the disappearing wonders of the world and the hidden worlds below our feet. In *High*, author and illustrator Jess McGeachin encourages us to look up this time, or rather to imagine the world far above us where aeroplanes fly, birds soar and mountains tower. It begins with a very simple message – that from a great height the world below us is put into perspective and can seem very small and fragile. It's a philosophical observation that was made popular in space exploration by an Apollo 8 astronaut watching the Earth rise over the Moon's horizon, and astronomers who photographed Earth from billions of miles away as Voyager 1 left the Solar System. But on several levels, this title feels much closer to home.

High begins by looking up into a deciduous woodland canopy at the wildlife – feathered and furred – that call the treetops home. Then it's to the trees themselves and across the world to the rainforests, where we get our first environmental message, how humans have flattened a third of all trees on Earth in just the last century. There's a segue into the increasing heights of skyscrapers and how they're constructed, and back to nature with prehistoric pterodactyls, butterflies and flocks. From there, *High* frequently switches from the natural world to heights that human technology allows us to explore despite the limitations of our biology: the peak of Everest, the cruising altitude of commercial airliners and, of course, space.

"There's plenty of fact and wonder about both the natural and technological world above us"

McGeachin is far from preachy with her environmental message, and there's plenty of fact and wonder about both the natural and technological world above us to make the reader pause to appreciate what we've got – and what we might do to hang onto it. Coupled with layered illustrations that play with silhouette and shadow to produce some evocative spreads, *High* has everything you'd want in a book to educate and entertain a primary school student.



WILDLIFE ANATOMY

THE CURIOUS LIVES AND FEATURES OF WILD ANIMALS

AUTHOR **JULIA ROTHMAN**
PUBLISHER **STOREY PUBLISHING LLC**
PRICE **£12.99 / $18.99**
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Discover the anatomical and behavioural diversity within the animal kingdom in this visual guide. Through beautiful illustrations, *Wildlife Anatomy* breaks down different aspects of the animal world, from habitats and food chains to individual spot patterns and claw anatomy. Each page is packed with facts that might surprise you. Did you know that Arowana fish can leap almost two metres above the water's surface to snatch insects from branches, or that cantil snakes wiggle their tails to lure prey? Along with some of the more charismatic animals that often appear in children's books, *Wildlife Anatomy* goes a step further and introduces its young audience to a whole host of new and exciting species, such as the aye-aye, fisher cat and fossa. Informative and fun, this book will have children returning to it time and time again to learn more about the world's animals

ECOSYSTEMS OF THE MEDITERRANEAN SEA

A PHOTOGRAPHIC DIVE BENEATH THE WAVES

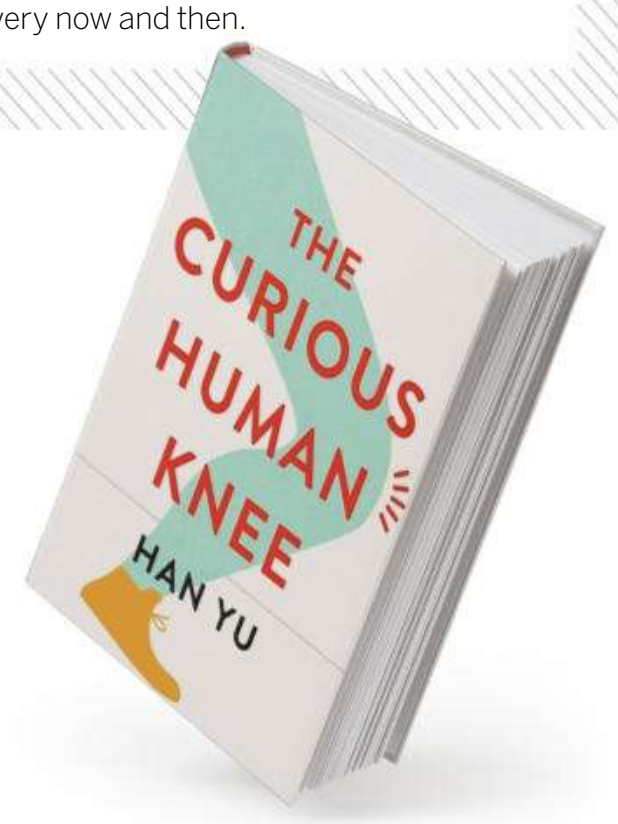
AUTHOR **GEORG GLAESER AND DANIEL ABED-NAVANDI**
PUBLISHER **SPRINGER PUBLISHING**
PRICE **£27.99 / $39.99**
RELEASE **OUT NOW**

From sunfish to sea sponges, no corner of the Mediterranean Sea has been left unexplored in this in-depth and intriguing book. Each page of *Ecosystems of the Mediterranean Sea* is flooded with stunning imagery. Sometimes we can often lose sight of the sheer diversity of life that exists underwater, but this mesmerising book offers a reminder of some of the fascinatingly weird and wonderful creatures that dwell in the Mediterranean Sea. Despite being photography-led, *Ecosystems of the Mediterranean Sea* doesn't disappoint in informing and educating. Each image is insightfully captioned with detailed facts about each species' life, and in some sections of the book, images have been grouped together to show comparable habitats and animals. Although it wouldn't be our first choice of reading material to pore over with a cup of tea and a biscuit, this book would still make a brilliant and eye-catching addition to your coffee table to thumb through every now and then.

THE CURIOUS HUMAN KNEE

THE EVOLUTION, SCIENCE, HISTORY AND SYMBOLISM OF THE KNEE

AUTHOR **HAN YU**
PUBLISHER **COLUMBIA UNIVERSITY PRESS**
PRICE **£25 / $29.95**
RELEASE **6 JUNE**



What makes you human? There are many body parts that perform complex functions on a daily basis, keeping us alive, moving and balanced. But one body part that's largely overlooked is the human knee. You may not acknowledge the work of your knee, but by reading this book you will learn new facts about the history, complexity and benefits of this joint.

The Curious Human Knee first explores the emergence of humans and the evolution of our knees. As a joint that stabilises us and keeps us upright on two legs, the knee is an essential part of what separates humans from apes. The author explains how the quick evolution of the knee – to support bipedal walking – contributed greatly to our species' early success and growth.

We all benefit from the complexity of these joints at the bend of our legs and the ease at which they operate. The knees expertly handle forces placed on them daily, absorbing the pressure of around three times your body weight. This means that, inevitably, the human knee is prone to injury. Knee pain can stem from many causes, and this book helps explain how the bones, cartilage, ligaments and tendons that make up your knee can suffer from tearing and stress. In addition, you will learn why the female body is more likely to suffer from a knee injury than a male's.

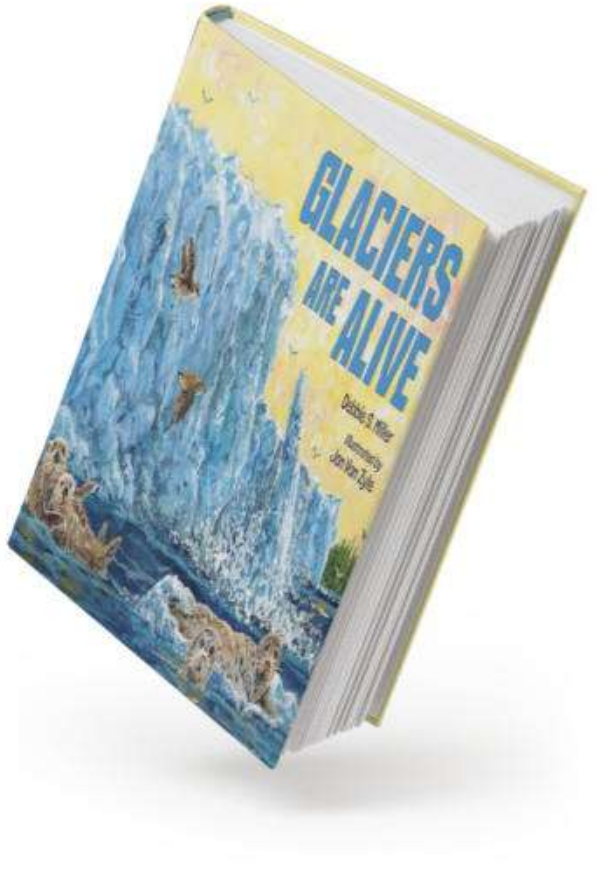
Despite packing in masses of fascinating science facts about this joint, *The Curious Human Knee* doesn't overwhelm with jargon and stats. It's written in an engaging and sometimes humorous tone, and incorporates the importance of the knee for a range of purposes, from sporting activities to symbolic gestures.

GLACIERS ARE ALIVE

MEET THE ANIMALS THAT CALL THIS ICE HOME

AUTHOR **DEBBIE S. MILLER**
ILLUSTRATOR **JON VAN ZYLE**
PUBLISHER **CHARLESBRIDGE**
PRICE **£16.99 / $17.99**
RELEASE **9 MAY**

For many young science lovers, a glacier is considered a slab of ice. *Glaciers Are Alive* is here to take a closer look and show us that they are teeming with life. From the pink algae blooms that thrive on glacial ice to the brown bears that walk across them and the seals that rest on their calved ice – these glaciers impact the life around them at all stages of their cycle. The process of formation, movement, calving and melting is described in a perfect level of detail for young readers, explaining how each step impacts life around them. The immersive imagery transports the reader to different stages of a glacier's progression and provides a snapshot of each animal's glacial interactions. Despite a bitterly cold environment, the illustrator has incorporated an assortment of bright, warming colours. *Glaciers Are Alive* will take you flying with the birds as they eat the plankton pulled to the surface by falling glacial pieces. It leaps into the air from glacial meltwater with a humpback whale and nests in rocks carved by glaciers with seabirds. By the last page, you'll consider glaciers not only as ice blocks that are melting with the warming planet, but as an essential environment for polar life.



BRAIN GYM

Give your brain a puzzle workout

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

EASY

9		5					1	
		3	5	6	1	8		
6	1	4			8	2	7	
			4	5	3		8	
			6		2			1
	5	6	1			4	3	
		7	8	1	6	9		
4				3	7		5	
8	2		9		5	7		

MEDIUM

4			5				7	
					2		6	5
2		6						1
	1	4		2		6	8	
	2	7	6		1	5	3	
5		8	7	3				
7	3						5	
						2		
	8		2	4	6	7		

HARD

	3			2				
					7			
4	6	9					1	2
			4			2		6
2		7			8			
	5	6				3		
				8			3	1
			5	6				4
		1				8	7	

Word search

Find the following words

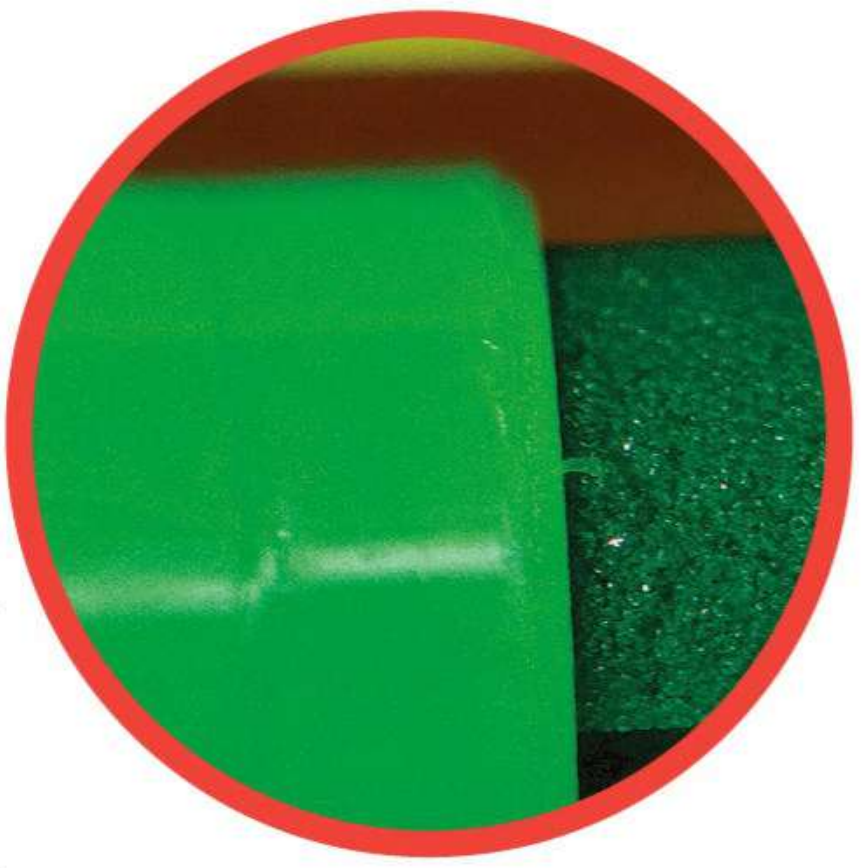
EXPLOSION
NUKE
SPY
BALLOON
SUIT
CROWN
AIR
FLAVOUR
DEEP
CLOUD
RIG
SHINGLES

R	A	D	O	O	L	N	W	O	R	C	E	N	I	P
B	I	U	T	S	O	W	F	R	I	D	Q	Y	U	D
L	R	G	C	L	U	A	D	L	J	X	E	C	S	H
T	K	E	X	P	L	O	S	I	O	N	D	L	A	Z
P	U	B	A	L	O	N	X	F	L	U	A	O	E	U
V	S	P	W	A	I	E	R	M	U	K	O	U	R	M
E	X	O	P	L	A	S	I	O	N	E	V	D	S	J
R	I	E	A	T	Y	N	U	X	G	E	K	C	U	E
F	E	R	B	I	P	H	G	E	I	F	L	A	I	O
D	U	R	F	L	A	V	O	U	R	S	H	Y	T	I
N	G	L	E	S	F	U	D	B	A	L	L	O	Q	N
E	K	U	M	P	C	R	O	M	W	D	E	P	E	S
E	X	Y	P	I	N	O	O	L	L	A	B	H	T	O
C	P	T	U	I	S	E	R	F	A	L	V	E	U	R
S	E	C	K	J	F	P	S	H	I	N	G	L	E	S

What is it?

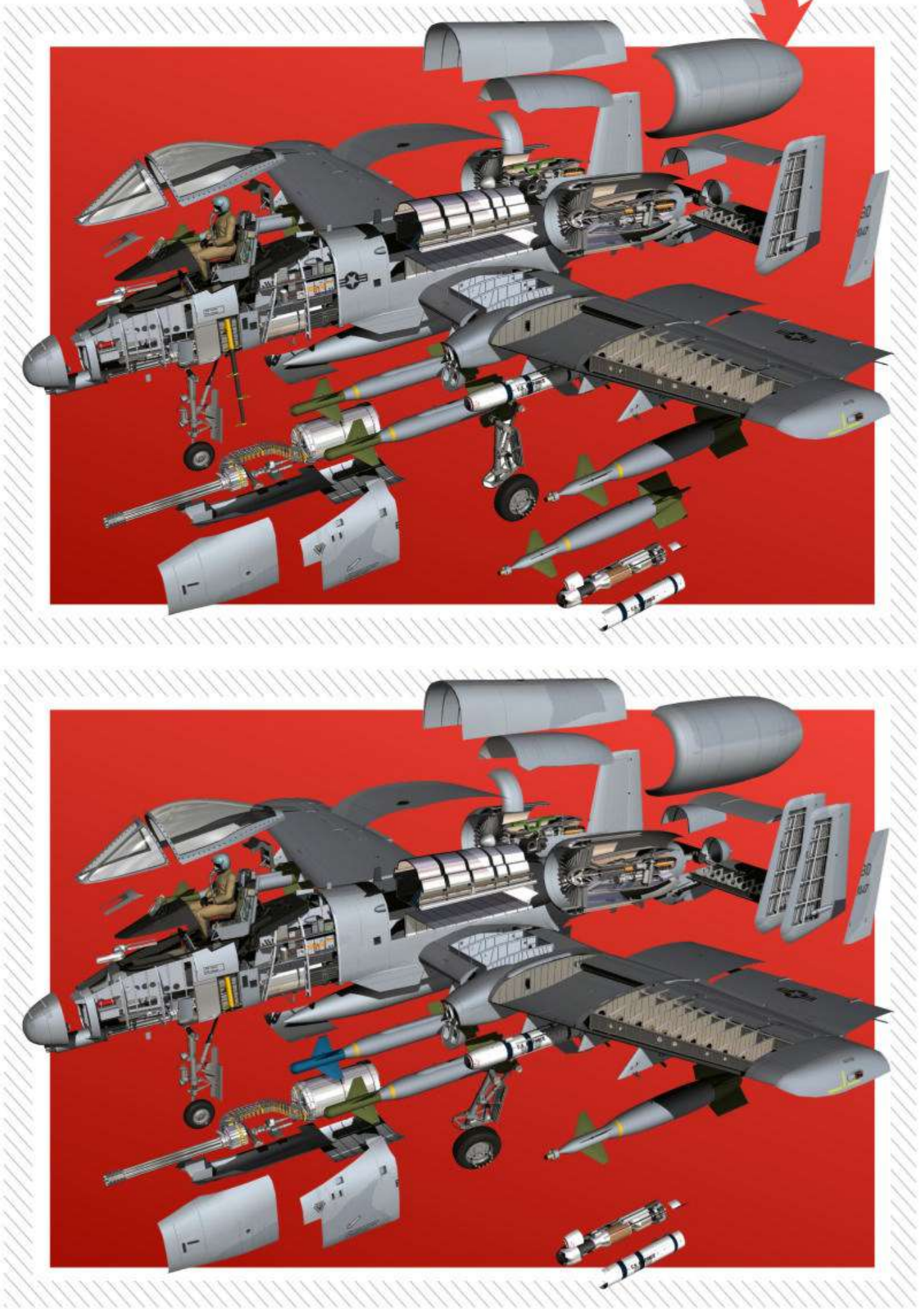
Hint:
Mark your words

A



Spot the difference

See if you can find all six changes between the images below



QUICKFIRE QUESTIONS

Q1 Which is the largest continent on Earth?

- Africa
- Antarctica
- Australasia
- Asia

Q2 How many bones are in a shark's body?

- 0
- 6
- 10
- 12

Q3 About how many times a day does your heart beat?

- 1,500
- 115,000
- 395,000
- 825,000

Q4 Which of these planets spins the fastest?

- Mercury
- Earth
- Mars
- Jupiter

Q5 What was sold as stomach medicine in the 1830s?

- Tomato ketchup
- Mayonnaise
- Strawberry jam
- Marmite

Q6 What can't you do with your eyes open?

- Sneeze
- Cough
- Burp
- Fart

Answers

Find the solutions to last issue's puzzle pages

Q1 206
Q2 EIGHT MINUTES
Q3 3,958 MILES
Q4 VOYAGER 1
Q5 SILICON VALLEY
Q6 A CHIMPANZEE

What is it?

BELLY BUTTON

Spot the difference

© Getty

HOW TO...

Practical projects to try at home

MAKE LIGHTNING

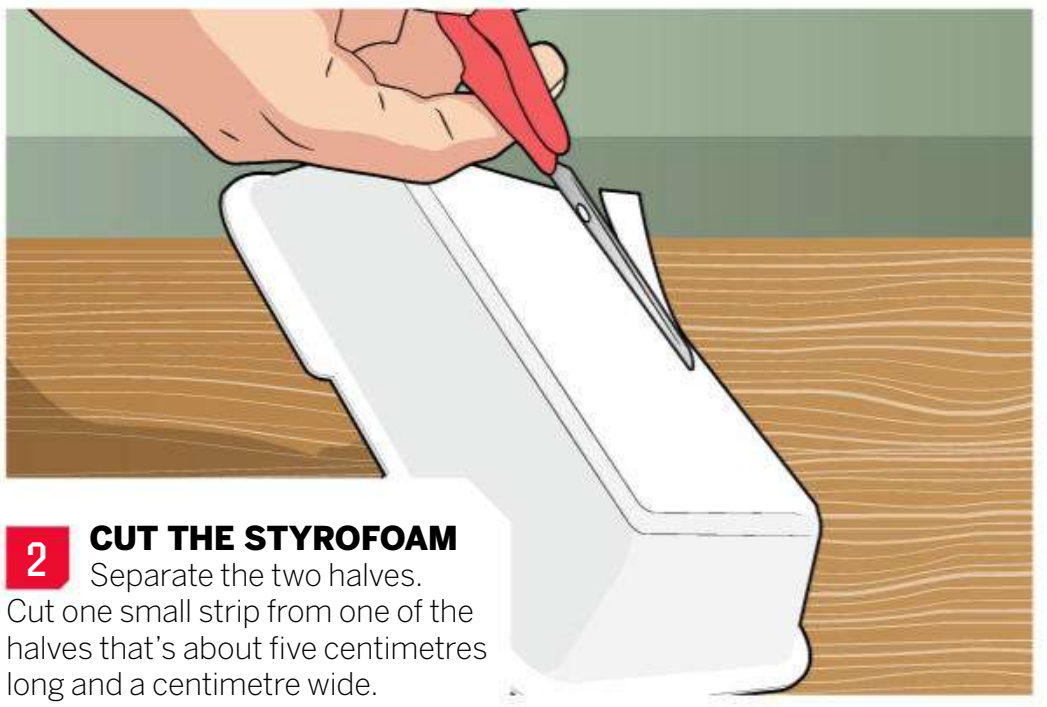
Learn about static science in this shocking weather simulation

KIT LIST

- Aluminium tray
- Wool cloth or sock
- Styrofoam plate or container
- Sticky tape
- Scissors

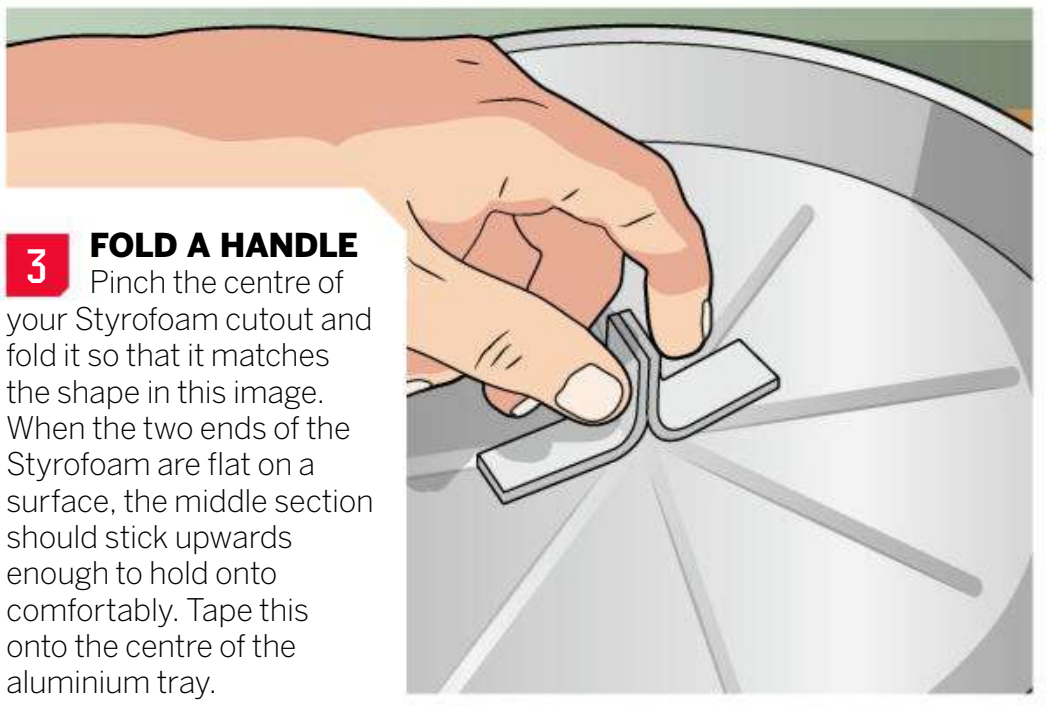
1 GATHER YOUR MATERIALS

Collect the materials and equipment listed. You can reuse old containers such as Styrofoam takeaway and aluminium pie dishes.



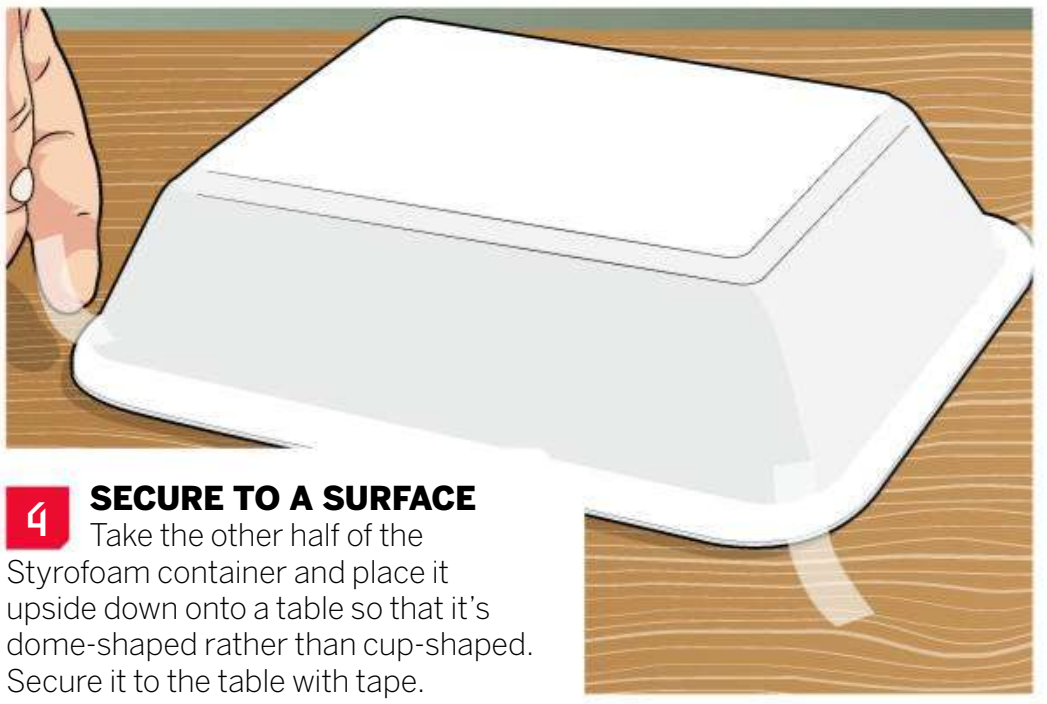
2 CUT THE STYROFOAM

Separate the two halves. Cut one small strip from one of the halves that's about five centimetres long and a centimetre wide.



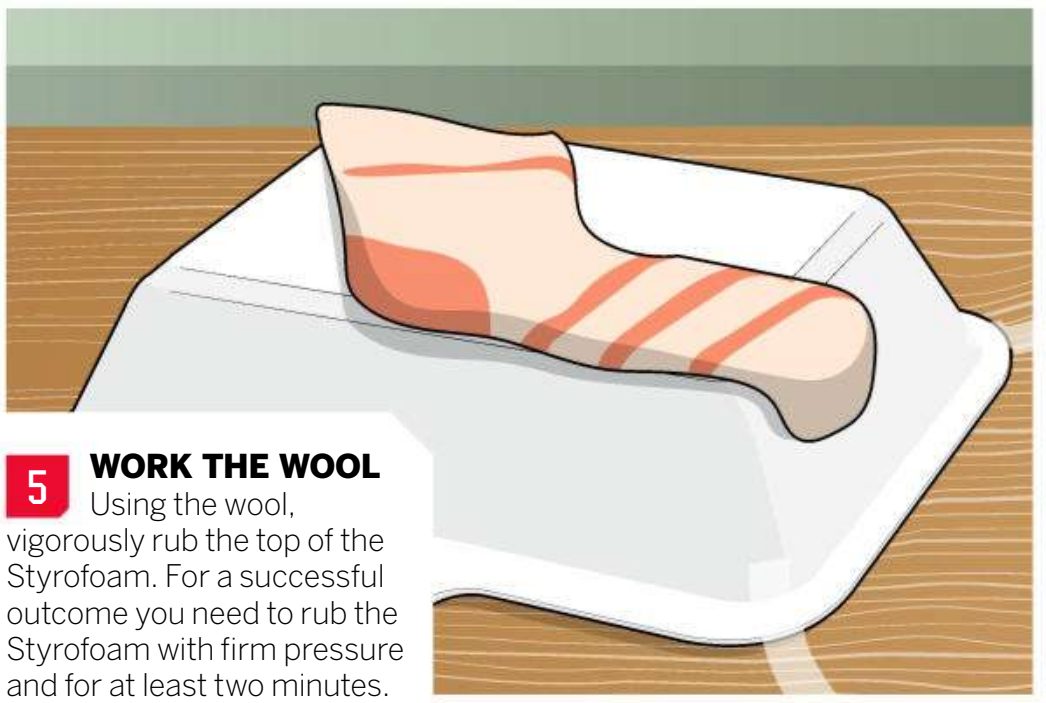
3 FOLD A HANDLE

Pinch the centre of your Styrofoam cutout and fold it so that it matches the shape in this image. When the two ends of the Styrofoam are flat on a surface, the middle section should stick upwards enough to hold onto comfortably. Tape this onto the centre of the aluminium tray.



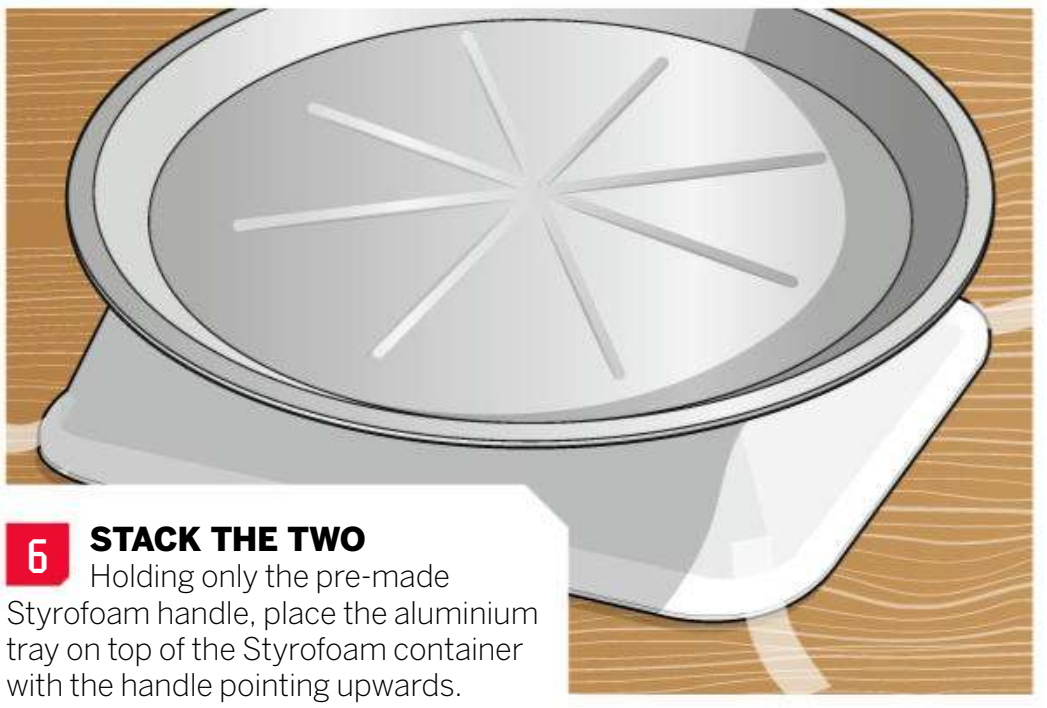
4 SECURE TO A SURFACE

Take the other half of the Styrofoam container and place it upside down onto a table so that it's dome-shaped rather than cup-shaped. Secure it to the table with tape.



5 WORK THE WOOL

Using the wool, vigorously rub the top of the Styrofoam. For a successful outcome you need to rub the Styrofoam with firm pressure and for at least two minutes.



6 STACK THE TWO

Holding only the pre-made Styrofoam handle, place the aluminium tray on top of the Styrofoam container with the handle pointing upwards.

DON'T DO IT ALONE!

If you're under 16, make sure you have an adult with you

7 CHOOSE YOUR TOOL

Decide whether you wish to feel the miniature lightning spark or not. If you don't want to feel a small shock, you should find a fork with a non-metal handle.

8 LET LIGHTNING STRIKE

Slowly move your finger or fork towards the aluminium tray. When you get close to the tray, you should see – and feel – a small bolt of electricity jump between the tray and your finger. Turn the lights off for a clearer view.

SUMMARY

Lightning strikes occur when negative electrical charges (electrons) at the bottom of a cloud are attracted to the positive charges (protons) on the ground below. In this experiment, the electrons of your finger are attracted to the protons of the aluminium tray. When you rub the wool onto the Styrofoam, electrons are transferred between materials, causing an electrical imbalance. Objects that have this imbalance are electrically charged. When the aluminium tray is in contact with the Styrofoam, it too takes this electrical charge, as metal is an electrical conductor. As you move your finger closer to the aluminium, the attraction between the protons and electrons becomes stronger. Eventually, the strength is so great that the electrons can flow through the air as they jump across the gap. This can be seen as a small bolt of electricity – or as millions of volts when experienced in a thunderstorm.

Had a go? Let us know!

If you've tried out any of our experiments – or conducted some of your own – let us know! Share your photos or videos with us on social media.

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INBOX

Speak your mind

HUMONGOUS HELICOPTERS

Dear **HIW**,
Thank you for the insightful article about monster vehicles in issue 174. I had no idea some of those existed, and kudos to the ingenuity of all those who develop, create and maintain such vehicles. In particular, mention of the heftiest helicopter was most intriguing. On the subject of helicopters, although 'stealth helicopter' might be a contradiction in terms, I certainly would enjoy seeing **How It Works** cover the topic, if you haven't already.
Stephen Parry

Thank you for your letter, Stephen. We're happy to hear these vehicles captured your attention, and you can expect to see more of some of the world's most extraordinary vehicles in our transport section. How It Works has featured various stealth vehicles in previous issues, such as stealth planes, ships and a feature on stealth technology. Stealth technology involves keeping an aircraft invisible to some degree. And in this issue, you can learn about some of the technologies used to keep the US president's plane undetected in the sky.

The US started producing stealth aircraft in the 1970s

LETTER of the MONTH

Many stealth aircraft use radar-absorbing materials to prevent radio waves that are emitted from another aircraft or ground-based radar dishes from being reflected and exposing their whereabouts. As you have done some of your own research into stealth aircraft, you may have noticed that many of them have unusual and angular designs. This is to reflect radar signals in different directions, making it harder to pinpoint the stealth aircraft's whereabouts and make it appear invisible or even as a different object in the sky.

QUESTION OF COLOUR

Dear **HIW**,
Since colours cannot be defined by words, is it possible that different people have different perceptions of colours?
Christopher Hu

This is a great question, and a definite possibility. We give colours names and view them as universal. But what you see as purple is very likely to vary with what someone else sees when they look at the same-coloured light. The light-receptive cells in the eyes of each person can vary significantly in number, causing slight differences in the colours we observe. Research has shown that our perceptions of colour may vary based on gender, national origin, ethnicity and geographical location.

The human eye can see around 10 million colours

WIN!

AN AMAZING PRIZE FOR LETTER OF THE MONTH

HIGH

What wonders are soaring far above your head? Come on a journey to meet treetop creatures, birds and people who ride the wind

BEHIND THE TEARS

Dear **HIW**,
Why do people cry? Why do children cry more? Is there a physical reason?
Chris Lucas

Eyes can water to clean themselves and wash out irritants, but when we cry for emotional reasons, it releases stress hormones and natural painkillers. Animals and humans give off subtle chemicals in the form of stress hormones when they cry, which can cause others to show empathy. Babies and young children cry more because this is the first way in which humans communicate. Without the ability to communicate feelings verbally, babies need to cry when in any form of distress or discomfort.

Babies cry when they are hungry, tired, uncomfortable, sick or in pain

NEXT ISSUE

ISSUE 177

ON SALE 11 MAY 2023

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When air-drying, corn needs to be hung up outside until its moisture content drops below 25 per cent

CORN QUESTION

Dear **HIW**,
When I visited a nearby village, I saw that many homes had bunches of corn hanging outside their doors. Why do people do this?
George Steer

Thank you for sharing your observation with us. Although we weren't there to see the way this corn was hanging or the geographic location, there are a couple of potential reasons why these villagers were hanging corn. One of the main reasons that corn is hung outside is to dry it in the air. This prevents the corn from spoiling and makes it easier to remove the kernels from the cob. In some areas, like in Kanazawa, Japan, corn is hung outside homes to bring the inhabitants good luck. And in other regions, such as Uttarakhand, India, the number of corn cobs hanging outside a home symbolises a family's wealth.

PAPER PONDERING

Dear **HIW**,
What does the ply on toilet paper mean? I know the higher the number the more expensive it is, but what does it measure?
Poppy Jenkins

Each piece of toilet paper is made up of individual sheets pressed together. This number is usually between one and four, with one being the weakest and four being the strongest and generally softer. As you have noted, one-ply toilet paper is the least expensive as it is of lower quality and the least absorbent. The sheets are usually glued together in two, three and four-ply paper, with special glue that prevents the toilet paper from tearing, doesn't harden the toilet paper and dissolves when it comes into contact with water.

On average, a person will use more than 20,000 sheets of toilet paper a year

WE ASKED YOU

This month on social media, we asked you: What's your favourite food flavour or flavour combination?

@TIRA.__.MISU

Wasabi-flavoured snacks are amazing

@CYRUSTHEVIRUSYEETER

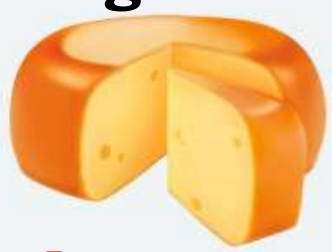
Some good old strawberries

@LOUISTYNDALL

Watermelon

@DOODLENEWS

I love chilli and garlic as seasonings together



@FATEMEH.JINYOUNG

Cheese and cacao are my two favourites

@JEANMCDOUGALL8333

Salted caramel

© Alamy / Getty

HOW IT WORKS

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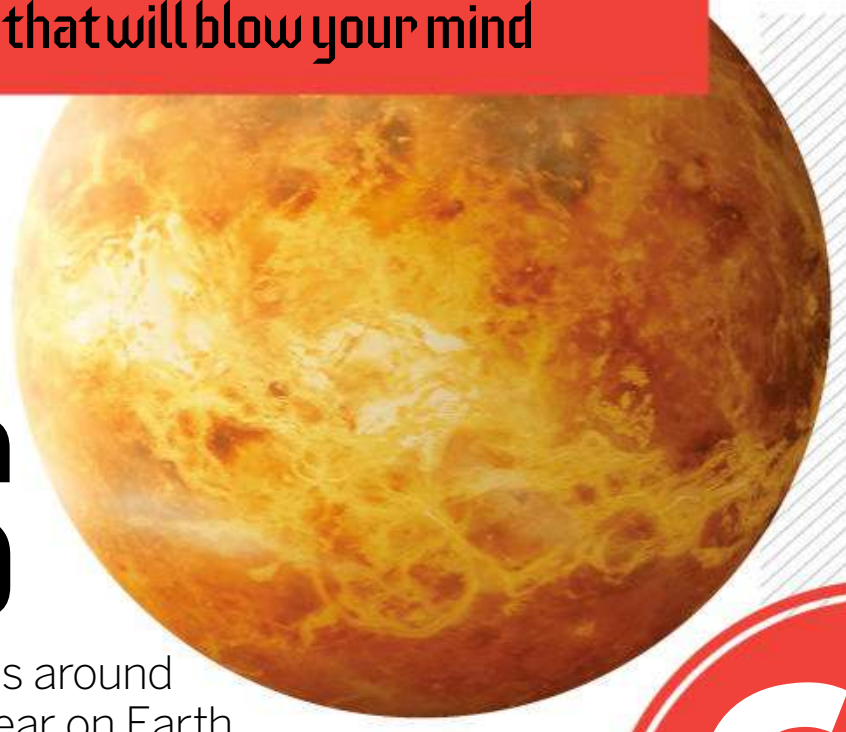
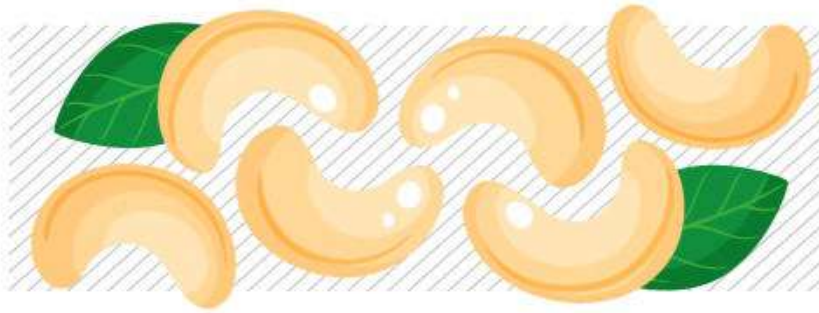
FAST FACTS

Amazing trivia that will blow your mind



234 DAYS

A day on Venus is around two-thirds of a year on Earth



CASHEW NUTS GROW ON CASHEW 'APPLES'

10 QUINTILLION

There are a lot of insects on Earth

12 YEARS OLD

Cleopatra became queen of Egypt before she was a teenager

37%

Over one-third of the world's population has never used the internet

67

The number of bacteria species in your belly button

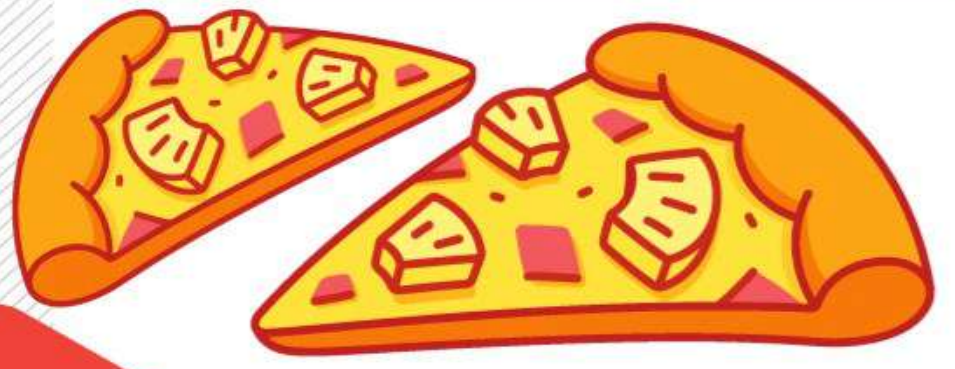
125%

Drinking alcohol increases your chances of snoring

$35 MILLION

The world's most expensive book, a first-edition *Book of Mormon*, sold in 2017

Some fish cough to clear their gills

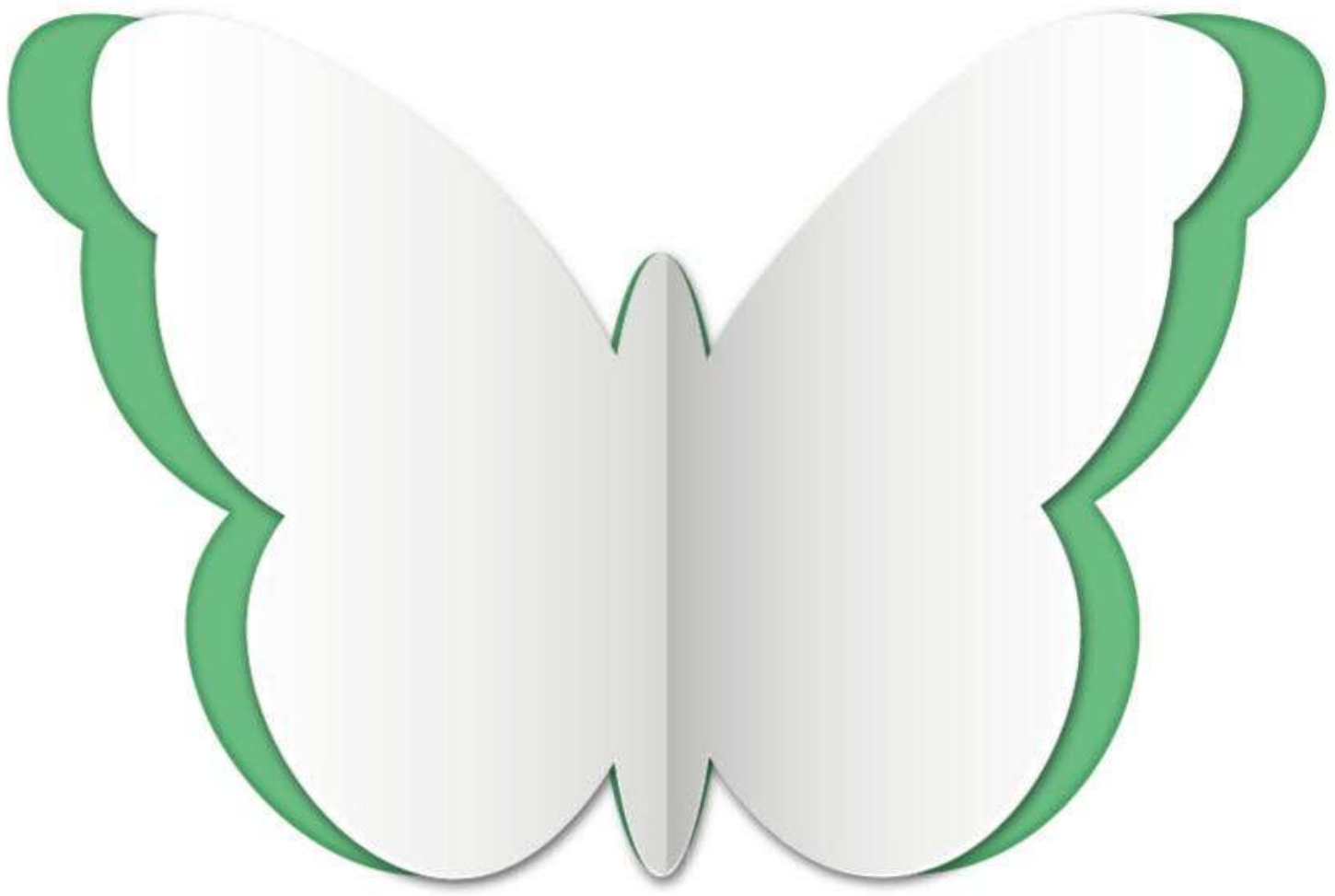


HAWAIIAN PIZZA WAS INVENTED IN CANADA

1 BILLION HOURS

We watch nearly 115,000 years' worth of YouTube videos every day

© Getty



PAPER & BIODIVERSITY

Forests cover 31% of the world's total land area and contain most of the world's earthly biodiversity. To ensure the long-term health of forests, the European paper industry counts on sustainable forest management as a source for its main raw material.

Source: FAO and UNEP, The State of World's Forests, 2020

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